공학석사 학위논문

Life-Cycle Environmental Implications of Eco-labelling for Rice Farming Systems

전과정평가 기법을 이용한 친환경농산물인증제도의 환경영향 평가

2017 년 2 월

서울대학교 대학원

생태조경・지역시스템공학부 지역시스템공학전공

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이 논문을 공학석사 학위논문으로 제출함
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2017 년 2 월

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Abstract

The regulations, standards, and certification systems for GHG reduction have recently been strengthened in response to climate change. In addition, environmental policies are being implemented pursuant to the 2015 Paris Agreement and in accordance with the reduction target of some countries.

Since the biggest goal in agriculture was pursued higher production until the 1990s, fertilizers and agricultural chemicals were used in abundance, which caused various environmental problems such as pest tolerance to insecticide, emissions of human and ecological toxic substances, and acidification of soil. Concern for such environmental problems began a movement toward sustainable agriculture. This concern has changed the paradigm of agricultural production systems from high input agriculture toward environmentally-friendly agriculture, which can minimize the environmental impact.

LCA methods began to be applied to the agricultural sector in 1996. Environmental impacts were evaluated for the production of single crops and/or inputs and outputs of agricultural materials including all materials used and produced in agriculture used until the 2000s. Since 2000, research has attempted to compare different agricultural production systems, such as conventional and organic systems. However, the majority of related studies focus only on the environmental impact of agricultural production activities, in particular on the effects on climate change due to the generation of GHG. It is difficult to find

research on other environmental impact categories, despite the fact that many categories are affected by agriculture.

The present study aimed to address this lack of research by quantitatively evaluating the environmental impacts of the rice production process in an environmentally-friendly agricultural product certification system (low-pesticide, non-pesticide, and organic farming) using the LCA method and comparing it to the impacts of conventional rice farming. Based on the LCA framework standardized by the International Standards Organization ISO 14040 series, the environmental impacts of the rice farming systems were evaluated and these results were analyzed and compared to the environmental impacts of rice production systems based on published databases in the U.S. and Europe.

The LCA in this study was in compliance with the ISO 14040 standard as prescribed by the International Organization for Standardization. GaBi software was used for analysis. First, in the goal and scope definition stage, the functional unit of rice cultivation was set at the farming of 1 kg of rice. The system boundary was established to include all nursery seedlings, cultivation, and harvesting procedures to produce 1 kg of rice. To construct the domestic LCI in South Korea, the agricultural and livestock product production cost survey data of the Statistics Korea of 2014 and the agricultural and livestock products collected by the rural development agency (RDA) were used. In the case of chemical agricultural materials, the maximum value of the standard allowable value of the environmentally-friendly agricultural

product certification system presented at Korea's Agricultural Products Quality Control Institute was used. In particular, an LCI for pesticide was constructed, especially in the case of synthetic pesticides, by using the pesticide-specific agricultural chemical information provided by the RDA, the source of the agricultural chemicals used for rice, the efficiency separating input, the analysis data of the air and water system, and the soil discharge route.

The climate change potential is evaluated as 1.01 kg CO_2-equivalents (100%) in conventional farming, 0.701 kg CO_2-equiv. (69%) in low-pesticide certified production, 0.537 kg CO_2-equiv. (53%) in non-pesticide certified production, 0.234 kg CO_2-equiv. (23%) in certified organic production. Based on the results, one can expect to reduce greenhouse gas emissions by more than 327 tons per year if about 10% of the current 4.22 million tons of conventional rice production were done by organic certification.

The potential for acidification is about 51% lower than the existing, conventional farming (6.33E-04 mole of H^+ equiv.) in certified organic production (3.13E-04 mole of H^+ equiv.). Regarding the eutrophication potential in the aquatic system, the reduction effect of organic (6.47E-09 kg P-equiv.) was very large compared to conventional production (6.03E-06 kg P-equiv.). Rice cultivation based on environmentally-friendly agricultural certification system was shown to be effective for reducing environmental impacts on other environments, such as human toxicity, as compared to conventional cultivation.

As a result of normalization, it was shown that substances discharged

in rice production have the greatest influence on human toxicity and climate change, of the various categories of environmental impact. With Weighting, the standard was set with "100" as conventional, the reduced pesticide certification (73.73), the pesticide certification (59.57), and organic certification (34.31).

The environmental impacts of the production of 1 kg of rice in South Korea, the United States, and Europe were compared based on LCI in the U.S. and Ecoinvent in Europe. With the United States as the standard (100), it was evaluated at 53.7 in Europe. In Korea, the results were 48.6 for conventionally cultivated rice, 35.8 for low pesticide cultivation, 28.9 for non-pesticide cultivation, and 16.7 for certified organic cultivation.

This research might be able to provide as basic reference for various agricultural policies such as marketing of agriculture and food enterprises in the future, environmental quality evaluation in the agricultural field, and environmentally-friendly agricultural direct payment. Especially, it is considered that active use can be made for improving the methodology and diffusion of environmental labels or carbon labeling system.

Keyword : Life Cycle Assessment, Sustainable agriculture, Environmental impact, Environmentally-Friendly Agricultural Products Certificate

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CHAPTER 1. INTRODUCTION

1.1. Background

Concerns about climate change have driven countries to strengthen their greenhouse gas (GHG) emission reduction regulations, guidelines, standards, and certifications (Parry, 2007; Haines et al., 2010; Leggett, 2011). The Paris Agreement, an agreement of the United Nations Framework Convention on Climate Change (UNFCCC) dealing with mitigation of GHG emissions, is a representative policy on climate change (OECD, 2015). The Paris Agreement, adopted by 195 countries in the Conference of the Parties (COP21) in regular session on December 12, 2015, replaced the Kyoto Protocol, which was adopted in 1997. Unlike the Kyoto Protocol, which obliged only developed countries to reduce GHG, the Paris Accord demands that each of the 195 participating nations-accounting for over 90 percent of global GHG emissions-adopt the reduction objective.

Several environmental policies have been established to meet the reduction target of GHG in various sectors, the agricultural sector being no exception (Smith et al., 2007; Dooley and Frelih-Larsen, 2015). Various environmental policies related to agriculture are currently in place (Weersink et al., 1998), including Eco-labelling for agricultural products (for example, carbon labeling and organic labeling), payments for watershed services (PWS) (watershed protection programs for

maintaining water quality and quantity), and best management practices (BMP) (for control of various pollutants during crop production).

Similarly, there are numerous policies aimed at the reduction of GHG emissions in the agricultural sector, targeting farm products (Smith et al., 2008; Friel et al., 2009). For example, the Codex Alimentarius (Latin for "food code"), put forth by the Codex Alimentarius Commission (CAC), an agency jointly run by the Food and Agriculture Organization (FAO) of the United Nations and the World Health Organization (WHO). This policy provides guidelines for the production, processing, labeling and marketing of food produced organically. A South Korean policy, which is a part of an Eco-labelling program with various farming systems, addresses carbon labeling and environmentally-friendly agricultural products certification. This certification has been effectively enforced for producers and consumers in South Korea.

Agriculture plays a role in both the sink and the source of carbon emissions. However, there is a high degree of uncertainty in the characteristics of agriculture and all agricultural activities require environmental consideration. The agricultural industry in the early 18th century aimed to improve crop productivity by using high input agricultural materials. Agriculture certification has become more important as agricultural systems have evolved due to environmental concerns (Commission of the European Communities, 1999; UN-DSD, 2000).

When evaluating the effect of environmental improvement, it is

important to consider the life cycle of agricultural productivity (Brentrup et al., 2003; Ryu and Kim, 2010). The life-cycle assessment (LCA) is one effective tool to evaluate life-cycle environmental implications in the field of agriculture. It is necessary to quantify the environmental influences of agriculture, to objectively assess them and reduce their negative impact, while keeping the positive functions of agriculture.

There are several certifications available globally, including carbon labeling in Europe, the United States, and Asia. Eco-labelling in the agricultural sector typically focuses on the carbon footprint and this labelling does not address other environmental concerns like acidification, eutrophication, etc. Quantitative evaluations are rare which study the effects on environmental improvement and on changing inputs involved in cultivation.

Korea's eco-friendly certification of agricultural products focuses on the absence of chemical fertilizers and pesticides used in cultivation. Comprehensive evaluations of the environmental conservation value of certified food paints an incomplete picture (Shim, et al., 2010). Such studies fail, for example, to differentiate between domestic, organic products and imported, organic' processed food. The fossil fuels and GHG emissions involved in transportation are not accounted for. To adequately evaluate the environmental conservation value of imported food, it is necessary to evaluate many elements, such as energy consumption, eutrophication and GHGs. These elements also apply to the assessment of the environmental conservation value of domestic, organic products and other agricultural products.

1.2. Research Objectives

The main purpose of this study is to evaluate the environmental implications represented in Eco-labelling of various agricultural systems: conventional, low-pesticide, non-pesticide and organic farming, specifically as they pertain to rice farming. For this purpose, a new set of rice farming inventory data is being developed from existing LCA studies on rice production, literature reviews, statistical data from local governments and international organizations, and technical reports on agriculture. The methods used are as follows:

(1) A life-cycle inventory of rice farming was constructed using numerous references and the LCA was conducted according to the ISO 14040 and ISO 14044 standards.

(2) The U.S. LCI database for American conventional rice farming and Ecoinvent database for European conventional rice farming were used to assess the environmental implications on conventional rice farming in the U.S. and Europe.

(3) The GaBi software was used for the computational implementation of the life cycle inventories for life cycle impact analysis of rice farming in South Korea.

(4) The environmental implications of Eco-labelling for Korean rice farming systems were compared to the impacts of conventional rice farming using the LCI provided in U.S. and Europe databases to identify how Korean eco-friendly rice farming practices compare to other countries' farming systems. These results quantitatively reviewed the environmental impacts of Korean rice farming.

CHAPTER 2. LITERATURE REVIEW

2.1. Eco-Labelling

Environmental labeling provides the environmental characteristics of products and services (D'Souza et al., 2007). This system promotes eco-friendly production and the consumption of eco-friendly products. It plays a role in efforts to reduce the consumption of energy and resources, and to reduce pollutants (Hong, 2011).

International Organization for Standardization (ISO) provides the suggestions, which are standards on 3 types of environmental labelling (ISO, 1999; ISO, 2016; ISO, 2006a) (Table 1).Type I labeling, also called Eco-labelling, is an environmental labeling system provided by trusted parties called certificate authorities. As a third party or person evaluates the producer's environmental standards, it is a more objective, and therefore more reliable, certificated system. Type II labeling provides general statements or symbols regarding products, such as "reusable," or "ozone-friendly." Like Type I labeling, a third party also evaluates Type III labeling; however, it is designed to complement a much broader range of indicators. The independent third party verifies the life-cycle inventory analysis of products and issues a product rating evaluation of eco-friendly indicators, such as natural resource use, energy use, stream flow, exhaust gas, and solid waste generation (D'Souza et al., 2007.).

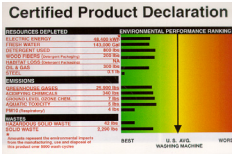
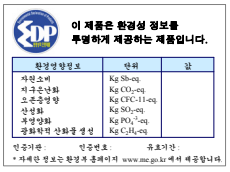
Loureiro et al. (2001) assessed consumer preferences of eco-labelled, organic, and regular apples and identified sociodemographic

characteristics affecting preferences. The study found that the eco-labelled apple is found to be an preferred choice among consumers. Loureiro and Hine (2002) evaluated consumer preferences for local, organic, and GMO-free potatoes. The study identified sociodemographic characteristics of consumers that affected consumer choice and compared the effects of different attributes on consumers' willingness to pay.

Harris (2007) described the test marketing of the first-ever fast moving consumer goods (FMCG), which is a sustainability certification of a product using LCA.

Thrane et al. (2009) evaluated the criteria applied by eco-labelling schemes for wild-caught seafood products and discussed these environmental impacts based on the ISO 14040 standard for LCA.

Table 1 Types of Environmental Labelling

Type	Type Ⅰ	Type Ⅱ	Type Ⅲ
ISO Standard	ISO 14024	ISO 14021	ISO 14025
Characteristics	· High reliability · Provided by trusted parties called certificate authorities	· Self declared environmental claims	· Environmental declarations · Provided by trusted parties about indicators
Naming	Eco Labelling	Self Declared Environmental Claims	Environmental Product Declaration
Examples	Blue Angle in Germany	SONY	 Certified eco-profile in the U.S
	Eco Mark in Japan	NEC	 EPD in Korea
	EU Flower in EU	Energy Star	–
	Eco-label in Korea	Energy Conservation	–

2.2. LCA on Rice Farming Systems

2.2.1. LCA on Agricultural Production Processes

LCA research for agricultural products is lacking in Korea; however, LCA in the agricultural field has been actively carried out in Europe and Japan since the Food Life Cycle Assessment European International Seminar in 1993.

The Swiss LCI database of agricultural crops is the most systematically and diversely constructed. Ecoinvent is an LCI database of agriculture and livestock production in general and includes information about agricultural crops, infrastructure, materials, machinery, etc. (Ecoinvent Center, 2004; Frischknecht and Rebitzer, 2005).

To investigate the use of resources and environmental burdens of major agricultural and livestock products produced or imported such as tomatoes, apples, strawberries, potatoes, cows, pigs, and chickens, the UK has evaluated environmental impacts through LCA (Dalgaard et al., 2003). The system evaluated was not limited to the production area, but included the regional distribution centers (RDC) of agricultural and livestock products.

The United States conducted LCA on soybean, maize, stem, and leaf-the main raw materials of biofuels-but developed a flow and leaching model of Nitrogen (N), Phosphorous (P), and Potassium (K) with particular focus on the use of pesticides and fertilizers (Powers, 2005; Pradhan et al., 2011).

A method to implement a top-down LCA for agriculture was developed by numerous researchers using the input-output analysis and evaluated based on the agricultural production method. Also, this method is used to analyze the methodology of the impact assessment on the agricultural sector and developed a weight factor in Japan (Harada et al., 2007). Based on the results of the LCA of agricultural crops and agricultural work systems executed in this way, an implementation manual of environmental impact assessment of agricultural cultivation was developed and applied to the sustainable agricultural production system and the agricultural production (Hayashi, 2013).

2.2.2. LCA on Rice Farming System

LCAs to evaluate environmental implication potential have been conducted in many countries. In the early days of applying LCA in agricultural fields (from 1996 to 2000), LCA were mostly conducted on the production of a single crop or the inputs and outputs of agricultural materials. However, since 2000, the main subject of LCA in the agricultural sector has been comparison of separate agricultural systems, such as conventional and organic farming (de Boer, 2003).

Breiling et al. (2005) conducted LCA to understand the environmental impacts potential of no-tillage cultivation on greenhouse emissions using LCA in Japan. The results showed that protection of rice production is required to counter the increase of greenhouse gas emissions in transportation, waste and domestic sectors and to minimize problems related to landscape, water and natural hazard management.

Roy et al. (2007) evaluated the potential of resource conservation and reduction effects on GHG of different parboiling processes in Bangladesh using LCA methodology. The results showed that every production process has negative effects on the environment and the environmental load varies from process to process.

Roy et al. (2008) also evaluated the typical quality and energy consumption of rice farming and constructed an LCI for various forms of rice consumed in Japanese households.

Blengini and Busto (2009) conducted an LCA that focused on carbon emissions of rice in Vercelli, Italy. The results showed that organic,

upland rice farming have the potential to decrease the environmental impacts; however, the environmental benefits reduced in the case of upland rice production and almost cancelled for organic rice due to the lower grain yields.

Yoshikawa et al. (2010) conducted an LCA for eco-friendly rice using a denitrification-decomposition model that applied a change in soil organic carbon or GHG emissions.

Thanawong et al. (2014) compared crop systems using rain-fed irrigated water to research the environmental performance of paddy rice production in Northern Taiwan using an LCA. The methodologies of techno-economic analysis and environmental impact assessment were combined to assess eco-efficiency in the paddy rice system. Wet-season, rain-fed systems are the most eco-efficient; dry-season irrigated systems are the least.

Brodt et al. (2014) carried out LCA for estimation GHG emissions in California rice production. When set the functional unit, one kilogram of milled, unpackaged rice produced in California, the 100-year global warming potential was 1.47 kg CO_2-equivalent per kilogram of milled rice.

Yan et al. (2015) used a LCA to estimate the carbon footprint of crop cultivation based on farm survey data in China. The farm carbon footprint of rice was estimated to be 6.0±0.1 ton CO_2 equivalents per ha.

Nunes et al. (2016) used LCA to estimate GHG emissions from rice production systems in Brazil though a comparison of organic farming

and minimal tillage. According to results analyzed by IPCC 2013, the global warming potential was highest for organic white rice farming, at 35.53kg CO_2 equivalents per kg of protein and the lowest was for the minimal white rice, at 15.80kg CO_2 equivalents per kg of protein.

CHAPTER 3. MATERIALS AND METHODS

3.1. Eco-labelling for Agricultural Products

3.1.1. Global Eco-labelling for Agricultural Products

Eco-labels are a labelling system for food and consumer products. Eco-labels for agricultural products are nearly identical to the common related non-governmental organization (NGO) definition of the rules for eco-labelling. Consumers prefer to consume food products that are not only produced in a manner that is safe for the environment, but that are also healthy, fresh, and more nutritious (Choi, 2014). For these reasons, many countries make an effort to offer clear information about the "green" characteristics of food products.

There are several examples of eco-labels of agricultural and food products. Biodynamics is an organic farming system that supplies farms with a living, dynamic, spiritual entity that attempts to bring food into balance. Certified Naturally Grown (CNG) is a grassroots alternative to the National Organic Program (NOP) of the United States Department of Agriculture (USDA) that puts less emphasis on some NOP rules while using NOP production practices as the basis for its own organic standards. "Environmentally-friendly" is a general term used to describe products or services that have resulted in minimal to no harm to the environment during production or processing.

There are about 170 countries that produce eco-friendly agricultural

products by organic farming, covering approximately 78 million ha. in farming area. Organic land and other eco-friendly land area is 43.1 million ha. and 35 million ha., respectively. Most other eco-friendly land form is wild collection, including forestry, farm, and grassland.

Organic products are concentrated produce in Oceania and Europe. The organic land area of Oceania is 17.3 million ha. and Australia accounts for 99% of this area, the highest production by organic farming. Europe accounts for 11.5 million ha. of organic land and the combined area of Oceania and Europe is 67% of the total.

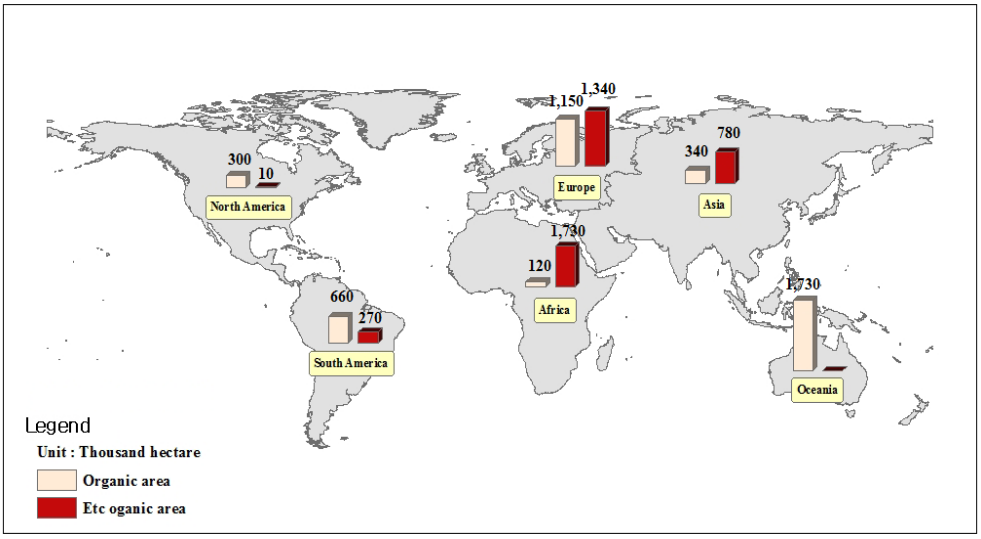


Figure 1 2015 Global Organic Farming Area

3.1.2. Korean Eco-labelling for Agricultural Products

According to the Environmentally-Friendly Agriculture Promotion Act in South Korea, "eco-friendly agricultural products" refers to products either not using or minimizing the use of synthetic pesticides, chemical fertilizers, antibiotics, bactericides, and other chemical materials, and through the recycling of the byproducts of farming, animal husbandry, and forestry. Through eco-friendly agriculture, the farming ecosystem and the environment are maintained and preserved when producing agricultural products. Eco-friendly agricultural products can be categorized according to production methods and materials used: organic, non-pesticide (pesticide-free), and low-pesticide agricultural products. Production of domestic, environmentally-friendly agricultural products has steadily increased since 2000, but it shows a tendency to decrease after 2009. Environmental agricultural product certification before 2009 was easy to register and production of environmentally-friendly agricultural products increased. However, since 2009, to address the problem of defective certification, the government has strengthened the system of certification management. Since the introduction in 2013 of a private certification body "strikeout system … law concerning environmentally-friendly agricultural industry development and management support for organic foods," the production volume of reliably environmentally-friendly agricultural products has gradually decreased.

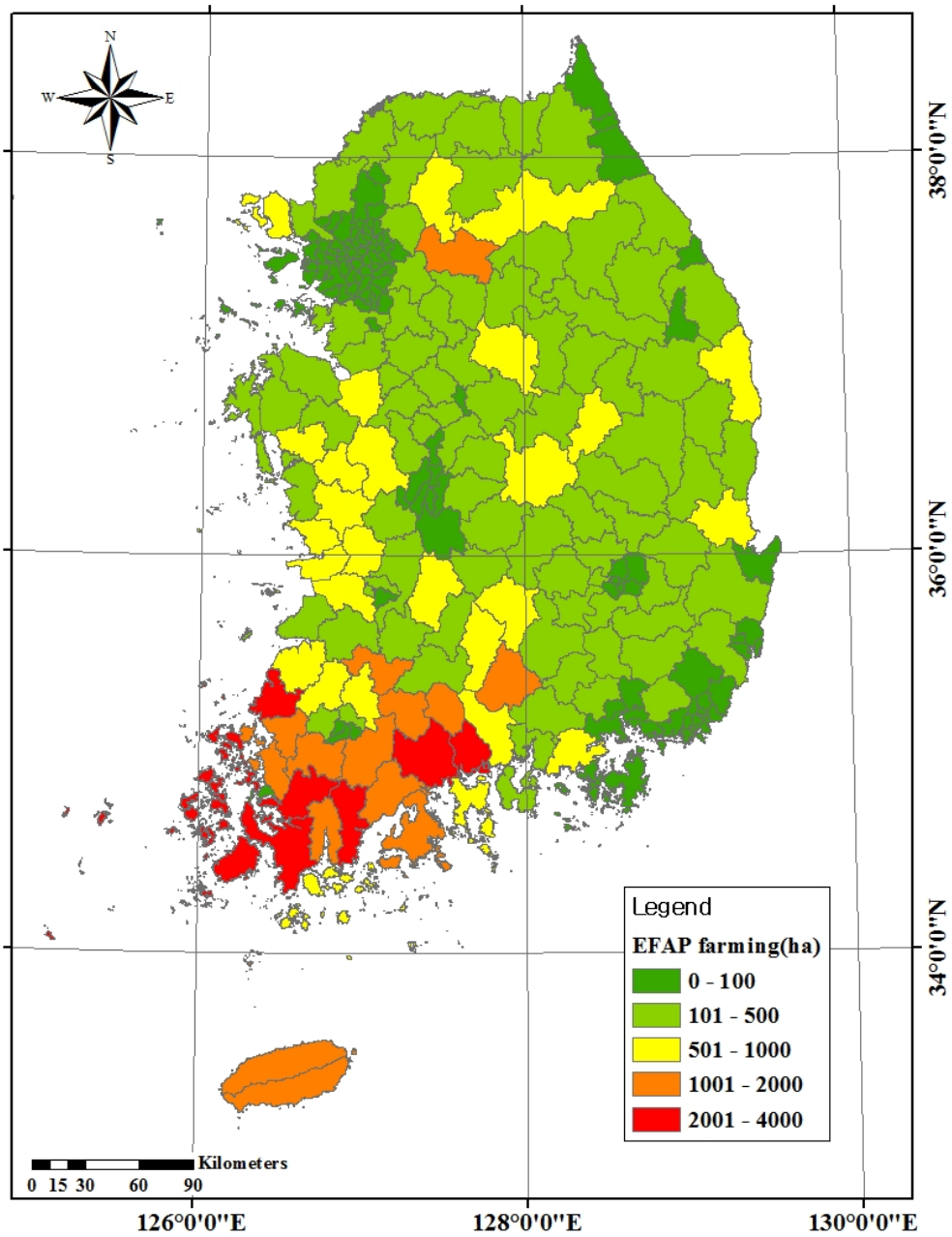


Figure 2 2015 Certified Environmentally-Friendly Farming Area

The Environmentally-Friendly Agricultural Products Certification (EFAPC) standards in South Korea are defined as follows (Table 2):
The low-pesticide agricultural standard includes agricultural products that have been cultivated without the use of organosynthetic agricultural pesticides, less than double dosage on the final day of application, and with less than one half of the recommended amount of applied fertilizer consisting of chemical fertilizer. This standard was abolished in South Korea in 2010; however, the warranty of the certificated mark was valid until 2015. Low-pesticide agricultural products sharply increased in production to 1,519,070 tons in 2008, but this figure fell rapidly later. In 2014, 253,348 tons were produced, a decrease of 32.5% from the previous year. Since 2011 the production of reduced agricultural-chemical products has begun to be less than that of non-pesticide products. Reduced agricultural-chemical agricultural products have discontinued new certification from 2010 because there is no differentiation from ordinary agricultural products, and existing farmers' production period has decreased with the effective period limited to 2015 (Figure 3).

The non-pesticide certification standard pertains to agricultural products that have been cultivated without the use of organosynthetic agricultural pesticides and less than 1/3 of the recommended amount of applied fertilizer consisting of chemical fertilizer. Non-pesticide agricultural products have shown a tendency to continuously decrease after recording their largest production volume at 1,039,576 tons in 2010. In 2014, agricultural chemicals agricultural products accounted for

the largest proportion of ecological agricultural products, accounting for 58% of the total production. The largest production area for these products was recorded at 101,657 ha. in 2011 but it decreased continuously to 65,061 ha. in 2014. It was found that the non-pesticide products in the southern province is high, with Haenam, Shinan, and Jindo-gun accounting for the highest production area (Figure 4).

The organic certification standard includes agricultural products that have been cultivated without the use of organosynthetic agricultural pesticides or chemical fertilizer. Organic agricultural products reached 168,256 tons in 2012, showing a tendency to continuously decrease after recording the maximum production volume. The shipment volume of organic agricultural products in 2014 showed production of 95,694 tons, 19.8% lower than the previous year. The largest production area was recorded at 25,467 ha. in 2012, but it decreased continuously, reaching 18,306 ha. in 2014. The production area is highest in parts of Jeju, Gangwon-do, Jeollabuk-do, and Jeollanam-do (Figure 5).

Table 2 Certificated Standard of Environmentally-Friendly Agricultural Products Based on Certification-related Legislation

		Low Pesticide Agricultural Products	Non-Pesticide Agricultural Products	Organic Agricultural Products
Chemical Fertilizer		less than 1/2 of the recommended amount of applied fertilizer	less than 1/3 of the recommended amount of applied fertilizer	without the use
Organosynthetic Pesticides	Dosage	less than 1/2 of the recommended amount of applied pesticide	without the use	without the use
	Spray time	less than double dosage on the final day of application	without the use	without the use
Note		Abolition of certification system in 2016	-	-

* Chemical Fertilizer: The fertilizer ingredient content recommended the administrator of Rural Development Administration (RDA) or Agricultural Technology Center (ATC) by farming fields.
* Fertilizer Usage: Only use of fertilizer allowed by Fertilizer Control Act.
* Crop dusting of organosysnthetic pesticide: Guide line for safe use of pesticides by Para. 2 of Art. 23 of the Agrochemicals Control Act

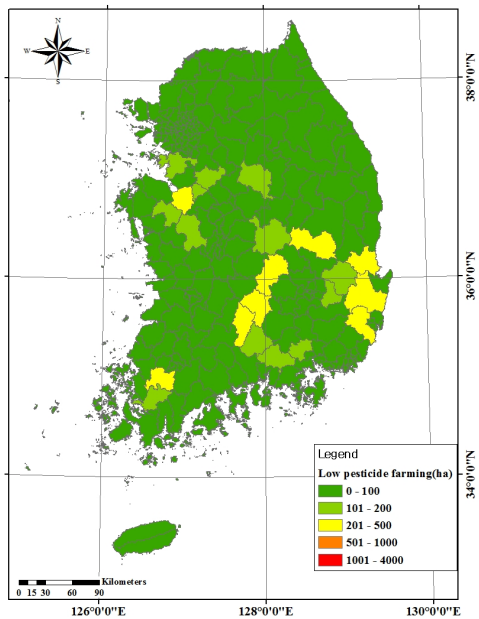


Figure 3 2015 Certified Low-Pesticide Farming Area

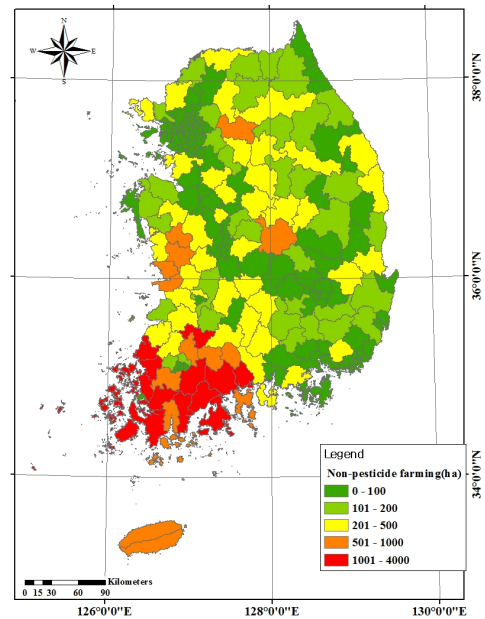


Figure 4 2015 Certified Non-Pesticide Farming Area

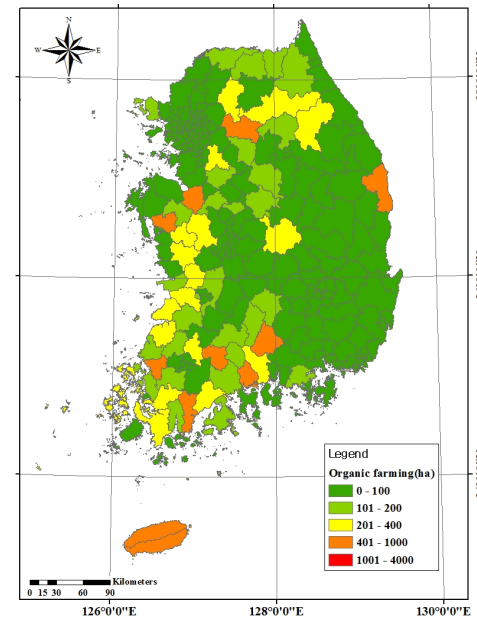


Figure 5 2015 Certified Organic Farming Area

3.2. Agricultural Product: Rice

Rice is one of the most important food crops in Asia. Although global production of rice has declined for decades, it was still an estimated 490.3 million tons in 2015 (FAO, 2016). The majority (87%) of rice comes from Asia, particularly China, India, Indonesia, the Philippines, Korea, and Japan. In addition, the majority of some countries' agricultural production is rice. For example, 90% of the total agricultural area in Cambodia is used for rice production.

As of 2011, worldwide consumption of rice was 557.3 million metric tons of paddy equivalent with the largest number of consumers by far in China, consuming 166.2 million metric tons of paddy equivalent and India consuming 131.2 million metric tons of paddy equivalent. The United States consumed 0.35 million metric tons of paddy equivalent, and production quantity was 8.3 million metric tons.

The per-capita annual consumption of rice in most Asian areas is high. For example, in 2014 the largest per-capita annual consumption of rice in China was 96.0 kg, in Korea it was 73.8 kg, and in Japan it was 58.5 kg. In contrast, the per-capita annual consumption of rice in the United States was only 12.3 kg, which was almost the lowest value and was 7.8 times lower than China's per-capita consumption (USA Rice Federation, 2014).

3.3. LCA Methodology on Agricultural Systems

3.3.1. Introduction

The LCA process has become standardized. The ISO 14040 series contains the major standards applicable to LCA (ISO, 1997). These standards provide ground rules for conducting LCA and define the terminology to be used. ISO 14040 series define LCA as

> A technique for assessing the environmental aspects and potential impacts associated with a product, by 1) compiling an inventory of relevant inputs and outputs of a product system, 2) evaluating the potential environmental impacts associated with those inputs and outputs, and 3) interpreting the results of the inventory analysis and impact assessment phases in relation to the objectives of the study.
> LCA studies the environmental aspects and potential impacts throughout a product's life (i.e. cradle-to-grave, cradle-to-gate, gate-to-gate) from raw material acquisition through production, use and disposal. The general categories of environmental impacts needing consideration include resource use, human health and ecological consequences.

The LCA definition provided in ISO 14040 also describes the four main elements of an LCA study framework (Figure 6): "Goal and

Scope Definition" (defining system boundary and functional unit), "Life Cycle Inventory Development" (compiling the inventory of relevant inputs and outputs), "Life Cycle Impact Assessment" (evaluating the potential impacts associated with the inputs and outputs identified in the life cycle inventory), and "Improvement Analysis" (interpreting the results in relation to the objectives).

The LCA on agricultural production systems makes it a rule to employ a "cradle-to-gate" perspective, considering everything from the extraction of the raw materials used in agricultural production to the production phase of agricultural products. In addition, the functional unit defines production for mass value of agricultural products. To be included in the analysis are the various sub-materials like energy (electricity, diesel, gasoline, etc.), pesticide, and fertilizer from the inputs in seedlings, cultivation, and harvest processes to producing agricultural products. Also included are emissions, such carbon dioxide, methane, nitrous oxide, and agricultural waste resources. The inputs of raw materials, energy, and agricultural materials affect resource depletion. LCA makes it possible to evaluate the environmental implications of emissions from chemical inputs for farming for various impact categories such as climate change, ecotoxicity, acidification, and eutrophication potential (Brentrup et al., 2004).

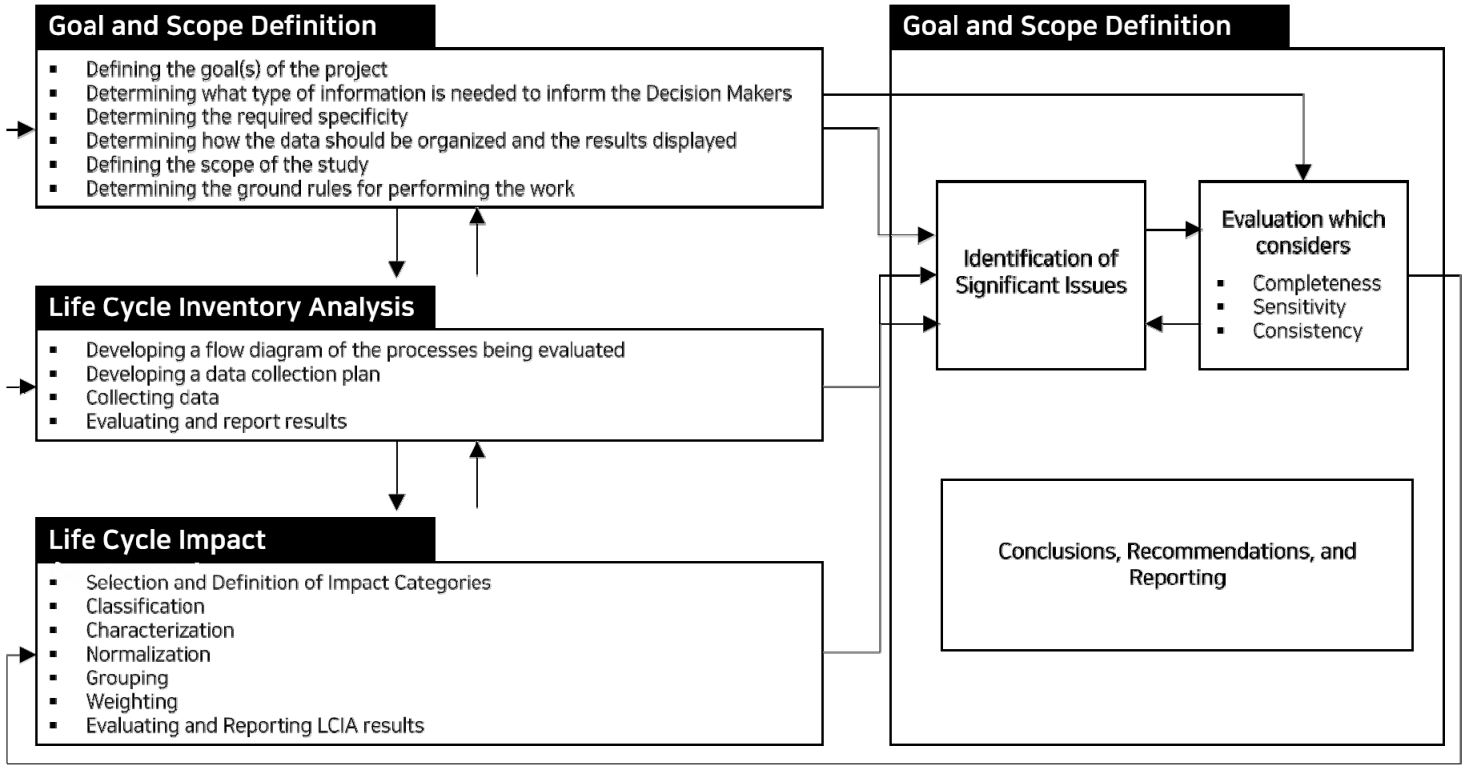


Figure 6 LCA Framework Defined by ISO 14040

3.3.2. Goal and Scope Definition

According to the ISO Standards for Life Cycle Assessment, the first step in LCA is the "Goal and Scope Definition" stage. This step sets the methodology of the specific LCA, ensuring uniformity throughout the analysis (Caffrey and Veal, 2013). This stage defines the purpose and method of including life cycle environmental implications into the decision-making process. To be determined in this phase are elements including: the information type needed to add value to the decision-making process, how accurate the results must be to add value, and how the results should be interpreted and displayed to be meaningful and usable.

In addition, there are basic decisions that should be made at the beginning of the LCA process to make effective use of time and resources. (See Table 3.)

The LCA process can be used to determine the environmental implication potential of a product, a process, or a service. The Goal and Scope Definition stage of LCA will determine the time and resources needed as well as guide the entire process to ensure the most meaningful results.

When setting the system boundary, there are various perspectives that may be employed in considering a product's life cycle. A cradle-to-grave perspective considers impacts at each stage of a product's life cycle, from the natural resources that are extracted from the ground and processed through each subsequent stage of

manufacturing, transportation, product use, recycling, and disposal (AI and NREL, 2010). Conversely, a cradle-to-gate perspective includes part of the product's life cycle, including material acquisition, through the production of the studied product but excluding its use or end-of-life stages (WBCSD and WRI, 2010).

According to the ISO standards about LCA, the functional unit is defined as a quantified implication of a product system to be used as a reference unit (ISO, 2006b). In the most frequently selected LCA studies of agricultural production, the functional units represent the mass of product (e.g., 1 kg of grain, biomass, fruit, etc.) (Nally et al., 2011; Gan et al., 2011; Gonzalez-Garcia et al., 2012; Murphy and Kendall, 2013; Alessandra et al., 2014) or the cultivated area (e.g., 1 ha of paddy, field, etc.) (Cellura et al., 2012; Negri et al., 2014).

Table 3 Six Basic Decisions at the Onset of the LCA

No.	Basic Decision
1	Define the goal of the project
2	Determine what type of information is needed to inform the decision-makers
3	Determine the required specificity
4	Determine how the data should be organized and the results displayed
5	Define the scope of the study
6	Determine the ground rules for performing the work

3.3.3. Life Cycle Inventory (LCI) Analysis

LCI is a process for quantifying energy and raw material requirements, atmospheric and waterborne emissions, solid wastes, and other release for the entire life cycle of a product, process, or activity. This inventory analysis is the phase of an LCA that involves the compilation and quantification of inputs and outputs for a product's system throughout its life cycle or for single unit processes. The inventory analysis includes data collection and the compiling of the data in an LCI table.

The Environmental Protection Agency published guidelines for LCI (EPA, 1993; EPA, 1995), providing the framework for performing an inventory analysis and assessing the quality of the data used and the results. These documents define the four steps of an LCI: development of a flow diagram of the processes being evaluated, development of a data collection plan, collection of data, and evaluation and reporting results. These steps are described below.

[Step 1] Developing a Flow Diagram

A flow diagram is a tool to map the inputs and outputs of a process or system. The initial boundaries established in the goal definition and scoping phase define what is to be included in a particular LCA and these are used as the system boundary for developing a flow diagram. Unit processes inside of the system boundary link together to form a complete life cycle profile of the required inputs and outputs such as

Table 4 Key Elements of Data Collection

No.	Key Elements of a Data Collection
1	Defining data quality goals
2	Identifying data sources and types
3	Identifying data quality indicators
4	Developing a data collection worksheet and checklist

material and energy to the system.

[Step 2] Developing an LCI Data Collection Plan

For the required accuracy of data, an LCI data collection plan should ensure that the quality and accuracy of data meet the expectations of the decision-makers when selecting sources for data to complete the LCI. The key elements of a data collection plan are outlined in Table 4.

[Step 3] Collecting Data

Collecting data involves a combination of research, site-visits and direct contact with experts generating large quantities of data. Commercially available LCA software packages can provide the level of data analysis required.

[Step 4] Evaluating and Documenting the LCI Results

It is important that the methodology used in the analysis is clearly

described and defines the analyzed systems for writing a report to present the final results of the LCI. The report document should describe both the set system boundaries and all assumptions made in performing the inventory analysis.

3.3.4. Life Cycle Impact Analysis (LCIA)

The Life Cycle Impact Analysis identifies the amount and evaluates the significance of the potential environmental impacts arising from the LCI (ISO, 1998).

The inputs and outputs are first assigned to impact categories and their potential environmental impacts quantified according to characterization factors. The LCIA involves several steps laid out by the ISO standard and described in more detail in the ISO 14042 standard. The ISO 14042 standard provides mandatory elements of an LCIA, including the selection, classification, and characterization of relevant impact categories. In addition, the optional elements of the study are normalization, grouping, and weighting. These steps are described in further detail below.

[Step 1] Selection and Definition of Impact Categories

The first step in an LCIA is to select the impact categories that will be considered as part of the overall LCA. This step should be completed as part of the initial goal and scope definition phase to guide the LCI data collection process and requires reconsideration following the data collection phase.

For an LCIA, environmental impacts are defined as the possible effects of the input and output streams of a system on human health, plants, and animals, or the future availability of natural resources. Typically, LCIAs focus on the potential impacts to three main

categories: human health, ecological health, and resource depletion.

The LCIA is a stage in an LCA which classifies and characterizes environmental indicators. Some suggested methodologies include international life cycle data system (ILCD), tool for the reduction and assessment of chemical and other environmental impacts (TRACI), and methodology of the center for environmental studies (CML). These methodologies differ in terms of representative substances among the materials of environmental load related to environmental categories (Table 5). ILCD provides more detail of environmental categories than the CML or TRACI methodologies. Some environmental categories are departmentalized in ILCD recommendations. For example, eutrophication is divided into terrestrial and aquatic categories.

[Step 2] Classification

After the relevant environmental impact categories are selected, the LCI results are assigned to one or more impact categories. The purpose of this classification step is to organize and possibly combine the LCI results into impact categories. If LCI items contribute to only one impact category, the procedure is a straightforward assignment. However, if LCI items contribute to more than one impact category, these factors should be classified as contributors to all relevant categories (Table 6).

There are two ways of assigning LCI results to multiple impact categories. One way to partition a representative portion of the LCI results to each impact category to which the LCI items contribute. This

Table 5 Comparison of the ILCD, CML, and TRACI Methods

ILCD method	Unit	TRACI	Unit	CML	Unit
Climate change	kg CO_2-equiv.	Global Warming Air	kg CO_2-equiv.	Global Warming Potential	kg CO_2-equiv.
Ozone depletion	kg R_{11}-equiv.	Ozone Depletion Air	kg CFC_{11}-equiv.	Ozone Layer Depletion Potential	kg R_{11}-equiv.
Acidification	Mole of H^+ -equiv.	Acidification Air	mole H^+-equiv.	Acidification Potential	kg SO_2-equiv.
Eutrophication, terrestrial	Mole of N -equiv.	Eutrophication Air	kg N-equiv.	Eutrophication Potential	kg PO_4-equiv.
Eutrophication, aquatic	kg P-equiv.	Eutrophication Water	kg N-equiv.	Photochemical Ozone Creation Potential	kg C_2H_6-equiv.
Human toxicity, cancer effects	CTUh	Smog Air	kg NO_X-equiv.	Human Toxicity Potential	kg DCB-equiv.
Human toxicity, non-cancer effects	CTUh	Human Health Cancer Air	kg Benzene-equiv.	Terrestrial Ecotoxicity Potential	kg DCB-equiv.
Particulate matter /Respiratory inorganics	PM2.5-equiv.	Human Health Cancer Water	kg Benzene-equiv.	Freshwater Aquatic Ecotoxicity Pot.	kg DCB-equiv.
Ionising radiation, human health	kBq U^{235}-equiv.	Ecotoxicity Air	kg 2,4-Dichlorophenoxyace	Marine Aquatic Ecotoxicity Pot.	kg DCB-equiv.

lonising radiation, ecosystems	kBq U^{235}-equiv.	Ecotoxicity Water	kg 2,4-Dichlorophenoxyace	Abiotic Depletion Potential	kg Sb-equiv.
Photochemical ozone formation	kg NMVOC equiv.	Human Health Criteria Air-Point Source	kg PM2.5-equiv.	-	-
Ecotoxicity (fresh water)	CTUe	Human Health Non Cancer Air	kg Toluene-equiv.	-	-
Ecotoxicity (terrestrial and marine)	CTUe	Human Health Non Cancer Water	kg Toluene-equiv.	-	-
Land use	kg C deficit	-	-	-	-
Resource depletion, water	m^3 water-equiv.	-	-	-	-
Resource depletion, mineral, fossil and renewable	kg Sb-equiv.	-	-	-	-

Table 6 Commonly Used Life Cycle Impact Categories

Impact Category	Scale	Examples of LCI Data
Global Warming/ Climate Change	Global	Carbon Dioxide (CO_2) Nitrogen Dioxide (NO_2) Methane (CH_4) Chlorofluorocarbons (CFCs) Hydrochlorofluorocarbons (HCFCs) Methyl Bromide (CH_3Br)
Stratospheric Ozone Depletion	Global	Chlorofluorocarbons (CFCs) Hydrochlorofluorocarbons (HCFCs) Halons Methyl Bromide (CH_3Br)
Acidification	Regional Local	Sulfur Oxides (SOx) Nitrogen Oxides (NOx) Hydrochloric Acid (HCl) Hydroflouric Acid (HF) Ammonia (NH_4)
Eutrophication	Local	Phosphate (PO_4) Nitrogen Oxide (NO) Nitrogen Dioxide (NO_2) Nitrates Ammonia (NH_4)
Photochemical Smog	Local	Non-methane hydrocarbon (NMHC)
Terrestrial Toxicity	Local	Toxic chemicals with a reported lethal concentration to rodents
Aquatic Toxicity	Local	Toxic chemicals with a reported lethal concentration to fish
Human Health	Global Regional Local	Total releases to air, water, and soil
Resource Depletion	Global Regional Local	Quantity of minerals used Quantity of fossil fuels used
Land Use	Global Regional Local	Quantity disposed of in a landfill or other land modifications
Water Use	Regional Local	Water used or consumed

is typically allowed in cases where the effects are dependent on each other. The other way is to assign all LCI results to all impact categories to which they contribute. This is typically allowed when the effects are independent of each other. For example, carbon dioxide (CO_2) and methane (CH_4) are both assigned to the impact category "global warming potential." Also, nitrogen oxide (NO_2) emissions can be classified as contributing to both "eutrophication potential" and "acidification potential;" therefore, the total flow will be fully assigned to both of these two categories. Conversely, sulfur dioxide (SO_2) is apportioned between the impact categories of "human health potential' and "acidification potential." Human health and acidification are parallel mechanisms, so the flow is allocated between the two impact categories.

[Step 3] Characterization

Characterization describes and quantifies the environmental impact of the analyzed product system. The third step in LCIA, impact characterization uses science-based conversion factors, or characterization factors, to convert and combine the LCI results into representative indicators of impacts on human and ecological health. The characterization factors also are commonly referred to as equivalent factors. Characterization provides a way to directly compare the LCI results within each impact category.

In short, characterization factors translate different inventory inputs into directly comparable impact indicators. Impact indicators are typically characterized using the following equation:

$$Impact\ Indicators_i = \sum_j (E_j \text{ or } R_j) \times CF_{i,j}$$

where $Impact\ Indicators_i$ is indicator value per functional unit for impact category i; E_j or R_j is release of emission j or consumption of resource j per functional unit; $CF_{i,j}$ is characterization factor for emission j or resource j contributing to impact category i.

For example, the reference substance for the impact category "global warming potential" is CO_2 and the reference unit is defined as "kg CO_2-equivalent." All emissions that contribute to global warming are converted to kg CO_2-equivalents according to the relevant characterization factor.

[Step 4] Normalization

Normalization is an optional LCIA tool used to express impact indicator data in a way that can be compared among impact categories. This procedure normalizes the indicator results by dividing by a selected reference value. This step involves displaying the magnitude of impact indicator results relative to a reference amount. The impact potentials quantify the potential for specific ecological impacts. The indicator results per functional unit (e.g., a kilogram of grain) are related to the respective indicator results for a defined reference area according to the following equation:

$$N_i = \frac{I_i}{NV_i}$$

where N_i is normalization result per functional unit for impact category i; $I_i$is indicator value per functional unit for impact category i; NV_i is the indicator value for a reference situation (e.g., per person in Europe) for impact category i, which also called a normalization value or factor.

In the normalization step, the impact category results are compared to references in order to distinguish what is normal from what is not. For normalization, reference quantities for a reference region or country during a time period are used. When the results of all impact categories are compared to their references, they can be compared to each other more easily, since it is possible to say which impact indicator result contributes more or less to the overall entity of the impact category.

There are various methods of selecting reference values, including total emissions or resource use for a given area that may be global, regional or local; total emissions or resource use for a given area on a per capita basis; the ratio of one alternative to another; and the highest value among all options.

Normalized impact indicator results are non-dimensional quantities that allow for comparison between different impact categories that show which impact category has a normal amount and which one is relatively larger.

ILCD normalization factors are provided in the ILCD handbook, a

Table 7 ILCD Recommended Normalization Factors for the EU-27

Impact category	Unit	Normalization Factor	
		Domestic	per Person
Climate change	kg CO_2 eq.	4.60E+12	9.22E+03
Human toxicity, cancer effects	CTUh	1.84E+04	3.69E-05
Human toxicity, non-cancer effects	CTUh	2.66E+05	5.33E-04
Acidification	mole H+ eq.	2.36E+10	4.73E+01
Particulate matter/ Respiratory inorganics	kg PM2.5 eq.	1.90E+09	3.80E+00
Ecotoxicity for aquatic fresh water	CTUe	4.36E+12	8.74E+03
Photochemical ozone formation	kg NMVOC eq.	1.58E+10	3.17E+01
Eutrophication, terrestrial	mole N eq.	8.76E+10	1.76E+02
Eutrophication, aquatic	kg P eq.	7.41E+08	1.48E+00

guide produced by the Institute for Environment and Sustainability in the European Commission's Joint Research Centre (JRC-IES) in 2011 (JRC-IES, 2011) (Table 7). Europe's normalization factors represent the total emissions of the E.U.-27 countries in 2010. Normalization factors are calculated per person using Eurostat data on the population of the E.U. (Aymard and Botta-Genoulaz, 2016).

[Step 5] Grouping

Grouping–the second optional LCIA element–assigns impact categories to one or more sets to better facilitate the interpretation of the results according to specific areas of concern. There are two possible ways to group LCIA data. Impact categories may be sorted on a nominal basis by characteristics, such as inputs and outputs or global, regional, or local spatial scales. Or impact categories may be ranked in a hierarchy, for example in high, medium, and low priority categories. Ranking is based on value choices; different individuals, organizations, and societies may have different preferences. Therefore, it is entirely possible that different parties will reach different ranking results based on the same indicator results or normalized indicator results.

[Step 6] Weighting

Weighting is also an optional element of the LCIA. This step assigns weight or relative values to the different impact categories based on value choices and not on scientific principles. Weighting is used to compare different impact indicator results according to their significance. Because weighting is not a scientific process, it is essential that the weighting methodology is clearly explained and documented.

Although weighing is widely used in LCAs, this step is the least developed of the impact assessment steps as well as the most likely to be challenged for integrity. Weighting generally includes identifying the underlying values of stakeholders, determining weights to place on

impacts, and applying weights to impact indicators.

Some accepted weighting factors are put forth by the Science Advisory Board (SAB) developed by the U.S. (U.S. EPA, 1990), Building for Environmental and Economic Sustainability (BEES), the stakeholder panel developed by Lippiatte, B.C. (2007), and the Netherlands Oil and Gas Exploration and Production Association (NOGEPA) panel by Huppes et al. (1997) (Table 8). Huppes et al. (2012) suggested adapted weighting factors that average the values of SAB, BEES, and NOGEPA.

[Step 7] Evaluate and Document the LCIA Results

After the environmental impact potential for each selected category has been calculated, the accuracy of the results should be verified. This accuracy must be sufficient to support the purposes for performing the LCA as defined in the goal and scope.

When documenting the results of the LCIA, some of the key limitations must be included such as lack of spatial resolution, lack of temporal resolution, Inventory speciation, and threshold and non-threshold impact.

Table 8 Adapted Weighting Sets Midpoint Weighting Factors

Interventions		Impact Category on Midpoint Level	Weighing Set			
			EPA Science Advisory Board (%)	BEES Stakeholder Panel (%)	NOGEPA (%)	Average Set Midpoint Panel (%)
Substance Emissions		Global warming	16	29	25	23
		Ozone depletion	5	2	4	4
		Acidification	5	3	5	4
		Eutrophication	5	6	10	7
		Photochemical ozone formation	6	4	6	5
		Cancer effects human toxicity	7	8	5	6
		Non-cancer effects human toxicity	4	5	3	4
		Particulate matter	6	9	5	7
		Freshwater ecotoxicity	11	7	15	11
		Ionizing radiation	11	3	5	6
Extraction	fossil fuels	Abiotic resource depletion	5	10	6	7
	minerals	Water intake	3	8	4	5
Land use		Habitat alteration	16	6	8	10
Total			100	100	100	100

3.3.5. Interpretation

Life cycle interpretation is a systematic technique to identify, quantify, check, and evaluate information from the results of the LCI and the LCIA and communicate them effectively. The International Standards Organization (ISO) has defined the objectives of life cycle interpretation (ISO, 1998b) in two categories. The first category includes analyzing results, reaching conclusions, explaining limitations, and providing recommendations based on the findings of the preceding phases of the LCA, then reporting the results of the life cycle interpretation in a transparent manner. The second category entails providing a readily understandable, complete, and consistent presentation of the results of an LCA study in accordance with the goal and scope of the study.

The ISO standard, especially ISO 14043, sets out the steps to conducting a life cycle interpretation, which are identified and discussed in Table 9 and are described in detail below.

Table 9 Key Steps to Interpretate the results of the LCA

Step	Key steps of a interpretation the results
1	Identification of the Significant Issues based on the LCI and LCIA
2	Evaluation which Considers Completeness, Sensitivity, and Consistency Checks
3	Conclusions, Recommendations, and Reporting

[Step 1] Identify Significant Issues

The first step of the life cycle interpretation phase of LCIA involves reviewing information from the first three phases of the LCA process in order to identify the data elements that contribute most to the results of both the LCI and LCIA for each product, process, or service, otherwise known as "significant issues."

Significant issues may include inventory parameters (e.g., energy use, emissions, and waste), impact category indicators (e.g., resource use, emissions, and waste), and essential contributions of life cycle stages to LCI or LCIA results, such as individual unit processes or groups of processes (e.g., transportation and energy production).

Determining these significant issues of a product system varies in complexity. Various approaches are recommended for identifying environmental issues and determining their significance, the such as contribution analysis, dominance analysis, and anomaly assessment. Contribution analysis compares the contribution of the life cycle stages or groups of processes to the total result and examines them for relevance. Dominance analysis uses statistical tools or other techniques such as quantitative or qualitative ranking to identify significant contributions to be examined for relevance. Finally, anomaly assessment entails observing unusual or surprising deviations from expected or normal results and examines them for relevance based on previous experience.

[Step 2] Evaluate the Completeness, Sensitivity, and Consistency of the Data

Evaluating the interpretation establishes the confidence and reliability of the results of the LCA. This is accomplished by completing completeness, sensitivity, and consistency checks to ensure that products and processes are fairly compared. The completeness check is a process for verifying whether information from the phases of a LCA is sufficient for reaching conclusions in accordance with the goal and scope definition (ISO, 2006). The sensitivity check is to assess the sensitivity of the significant data elements that influence the results most greatly. The consistency check evaluates the consistency of system boundaries, data collection, assumptions, and data allocation to impact categories for each alternative (ISO, 2006).

[Step 3] Draw Conclusions and Recommendations

The objective of this step is to interpret the results of the LCIA to determine which product or process has the least impact to human health and the environment overall, as well as the least impact to one or more specific areas of concern as defined by the goal and scope of the study.

If an LCIA stops at the characterization stage, its interpretation is less clear-cut. The conclusions and recommendations rely on balancing the potential human health and environmental impacts in light of the study's goals and stakeholders' specific concerns.

It is important to draw conclusions and provide recommendations

based on the facts, exclusively. Understanding and communicating the uncertainties and limitations of the results is equally as important as the final recommendations.

CHAPTER 4. LCA OF RICE FARMING SYSTEMS IN SOUTH KOREA

An LCA of eco-labelling of rice farming systems in Korea was conducted according to international standards of the environmental evaluation of products, particularly the ISO 14040 series, established by the International Organization for Standardization (ISO).

4.1. Goal and Scope Definition of Korean Rice Farming Systems

The goal of this study is to evaluate the environmental implications of eco-labelling in South Korean rice farming systems by conducting an LCI and performing a life-cycle impact analysis of eco-labelling for conventional, low-pesticide, non-pesticide, and organic rice farming systems.

Agricultural products are generally based on a mass reference of one kg of output of farm products. For purposes of the present analysis, the functional unit was set at 1 kg of paddy rice production, as measured in an unpackaged state at the farm exit gate.

The system boundary in this study was established using a cradle-to-farm gate (CtG) perspective. The agricultural system generally consists of seeding, preparation of the soil, cultivation, and harvest. Various materials are needed to produce agricultural products, including raw materials (e.g., seeds and nursery), sub-materials (e.g., agricultural

pesticides, fertilizers, and other agri-materials), and energy (e.g., electricity, diesel, and coal). Rice production causes emissions into the atmosphere, hydrosphere, and soil as well as solid wastes.

The life-cycle of rice production includes four stages: pre-production, production, consumption, and disposal. Rice farming pre-production includes inputs of farming systems such as agricultural pesticides, fertilizers, and fuel. The production stage refers to all phases associated with cultivation and harvest; for example, sterilizing seeds, plowing rice fields, planting rice, spraying agricultural pesticides and fertilizers, harvesting, drying cereals, and polishing. The consumption stage includes manufacturing, packaging, distribution, and consumption of produced rice. The disposal stage involves treatment and disposal phases: making fodder, composting, and methanation.

In general, CtG is the standard system boundary for crop production systems. However, the system boundary is set up for the present study according to a GtG principle excluding the consumption and disposal stages, as endemic databases for chemical materials used in agricultural sector have not been established yet in South Korea. The system boundaries for rice farming systems are illustrated in Figure 7.

The results of this study may be useful to executives of the agricultural sector, the government, experts in the agricultural field, and researchers in the field of agri-food. Furthermore, the results may be used as a database for the introduction of an Environmental Declaration of Products in the agri-food sector. This database would be helpful for constructing sustainable agricultural systems.

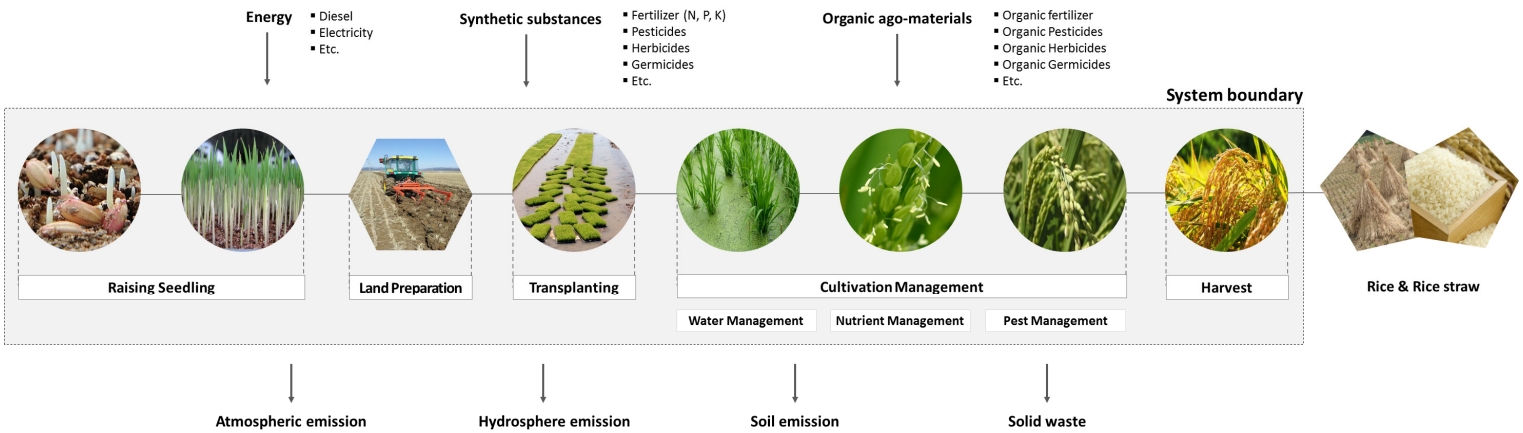


Figure 7 System Boundary of Rice Production: Cradle-to-Farm Gate Perspective

4.2 LCI of Korean Rice Farming Systems

In preparation for collecting data as established in the goal and scope definition, an LCI was conducted to derive a quantitative input-output inventory based on ISO 14041 standards. To set up the LCI for conventional rice farming, some statistical survey data from the Agricultural Production Cost Survey (APCS) and the Income of Agricultural and Livestock Products (IALP) in South Korea were used. The standard rate of fertilizer was provided by the Rural Development Administration (RDA).

For data on the amount of ago-chemical materials used in low-pesticide, non-pesticide, and organic rice farming systems, the maximum amount of standard permissible value as suggested by the National Agricultural Products Quality Management Service (NAQS) in South Korea was used.

The study referenced the RDA's information regarding agricultural chemicals used in the production of agricultural products to conduct the LCI of organosysnthetic agriculture chemicals used in rice farming. The LCI of pesticide used the original ingredients of agricultural chemicals, the amounts of active components of the chemicals, and those excretion pathways to atmospheric, hydrosphere, and soil.

The study used the agriculture light and heat expenses data from the Income of Agricultural and Livestock Products (IALP) published by the RDA for figures on energy consumption. The publication includes information about consumption of electricity for agriculture; oil types

such as diesel, gasoline, and kerosene; as well as amounts of atmospheric emissions when these are used in farming. In general, only physical inputs and outputs of rice farming were quantified, with the exceptions of environmental loads related to manufacturing agricultural machinery, economic costs, inputs of man-power, and construction of agriculture infrastructures such as agricultural reservoirs, irrigation canals, and roads.

The total amounts of fertilizer used in rice farming are as follows: 1.53E-02 kg in conventional farming, 7.64E-03kg in low-pesticide farming, 5.05E-03kg in non-pesticide farming per 1 kg of rice. The organosysnthetic agricultural chemicals used, including germicide, insecticide, and herbicide, are as follows: 1.05E-03kg in conventional farming, 5.27E-04kg in low-pesticide farming per 1 kg of rice, and none in non-pesticide and organic farming. In addition, vinyl and non-woven fabric are used in equal amounts in all rice farming systems (Table 10).

Table 10 Inventories of Inputs for 1 kg of Rice Cultivation in Korea

Entries for cultivation			Quantity			
			Conventional	Low Pesticide	Non Pesticide	Organic
Fertilizer	Urea	kg	1.25E-03	6.26E-04	4.13E-04	0.00E+0
	Ammonium sulfate	kg	6.48E-04	3.24E-04	2.14E-04	0.00E+0
	Fused phosphate	kg	2.03E-04	1.02E-04	6.72E-05	0.00E+0
	Fused superphosphate	kg	9.94E-06	4.97E-06	3.28E-06	0.00E+0
	Potassium chloride	kg	1.83E-04	9.13E-05	6.02E-05	0.00E+0
	Potassium sulfate	kg	1.42E-05	7.11E-06	4.70E-06	0.00E+0
	Calcium carbonate	kg	1.82E-03	9.08E-04	5.99E-04	0.00E+0
	calcium silicate	kg	2.76E-03	1.38E-03	9.12E-04	0.00E+0
Compound fertilizer	Nitrogen fertilizer	kg	3.17E-03	1.58E-03	1.05E-03	0.00E+0
	Phosphorous fertilizer	kg	2.64E-03	1.32E-03	8.72E-04	0.00E+0
	Potassium fertilizer	kg	2.60E-03	1.30E-03	8.58E-04	0.00E+0
Germicide	Thio-carbamate-compound	kg	6.64E-06	3.32E-06	0.00E+00	0.00E+0
	Acetamide-anillide-compound	kg	2.32E-07	1.16E-07	0.00E+00	0.00E+0
	Benzimidazole-compound	kg	1.17E-06	5.85E-07	0.00E+00	0.00E+0
	Cyclic N-compound	kg	8.86E-06	4.43E-06	0.00E+00	0.00E+0
	Organophosphorus-compound	kg	1.46E-04	7.29E-05	0.00E+00	0.00E+0
	Pesticide unspecified	kg	1.52E-04	7.59E-05	0.00E+00	0.00E+0
Insecticide	Thio-carbamate-compound	kg	2.19E-04	1.10E-04	0.00E+00	0.00E+0
	Organophosphorus-compound	kg	6.50E-05	3.25E-05	0.00E+00	0.00E+0
	Pesticide unspecified	kg	1.31E-04	6.53E-05	0.00E+00	0.00E+0
	Pyretroid compound-compound	kg	1.21E-06	6.07E-07	0.00E+00	0.00E+0

Table 10 Inventories of Inputs for 1kg of Rice Cultivation in Korea (Continue)

Entries for cultivation			Quantity			
			Conventional	Low Pesticide	Non Pesticide	Organic
Herbicide	Sulfonyl urea-compound	kg	7.57E-06	3.79E-06	0.00E+00	0.00E+0
	Thio-carbamate-compound	kg	6.75E-05	3.38E-05	0.00E+00	0.00E+0
	Benzo thia-diazole-compound	kg	2.47E-05	1.23E-05	0.00E+00	0.00E+0
	Dinitroaniline-compound	kg	2.44E-06	1.22E-06	0.00E+00	0.00E+0
	Diphenylether-compound	kg	3.60E-06	1.80E-06	0.00E+00	0.00E+0
	Organophosphorus-compound	kg	5.16E-07	2.58E-07	0.00E+00	0.00E+0
	Pesticide unspecified	kg	2.09E-04	1.05E-04	0.00E+00	0.00E+0
	Phenoxy-compound	kg	5.89E-06	2.95E-06	0.00E+00	0.00E+0
	Triazine-compound	kg	6.32E-07	3.16E-07	0.00E+00	0.00E+0
Deposition	Sulfonyl urea-compound	kg	6.73E-11	3.37E-11	0.00E+00	0.00E+0
	Thio-carbamate-compound	kg	9.39E-08	4.69E-08	0.00E+00	0.00E+0
	Bipyridylium-compound	kg	3.26E-07	1.63E-07	0.00E+00	0.00E+0
	Cylic N-compound	kg	8.07E-07	4.03E-07	0.00E+00	0.00E+0
	Pesticide unspecified	kg	3.32E-04	1.66E-04	0.00E+00	0.00E+0
Energy	Electricity	kW	4.11E-03	3.61E-03	2.30E-03	2.05E-03
	Diesel	m^3	5.18E-03	4.55E-03	2.90E-03	2.59E-03
	Kerosene	m^3	7.61E-04	7.61E-04	7.61E-04	7.61E-04
	Gasoline	m^3	2.03E-03	1.79E-03	1.14E-03	1.02E-03
Agrimaterials	Vinyl (HDPE)	kg	1.86E-05	1.86E-05	1.86E-05	1.86E-05
	Vinyl (LDPE)	kg	2.30E-03	2.30E-03	2.30E-03	2.30E-03
	Non-woven fabric	kg	2.92E-03	2.92E-03	2.92E-03	2.92E-03

4.3. LCIA of Korean Rice Farming Systems

4.3.1. Classification

Classification assigns inventory databases to environmental categories. The inventory results are sorted into environment issues and indicators called "impact categories." The indicators denote the potential of environmental impacts to reflect total emissions or resources use in each category.

It is clear that agricultural production and food processing contribute to environmental implications on climate change potential, acidification potential, and eutrophication potential, significantly (Pardo and Zufia, 2012; Ruviaro et al., 2012; Saarinen et al., 2012).

The International Reference Life Cycle Data System (ILCD) Recommendations present several impact categories. Of these, the following impact categories were selected to evaluate the environmental implications of rice farming systems (Table 11). Those categories related to agricultural production are climate change potential (CCP), terrestrial eutrophication potential (TEP), aquatic eutrophication potential (AEP), and acidification potential (AP). Other categories are cancerous human toxicity potential (HTP-CE), non-cancerous human toxicity potential (HTP-NCE), particulate matter or respiratory inorganics potential (PMP), photochemical ozone formation potential (POFP), and freshwater aquatic ecotoxicity potential (FAEP).

Table 11 Recommended and Selected Impact Categories

Impact category	Indicator	Unit
Climate change	Radiative forcing as Global Warming Potential (GWP100)	kg CO2-equiv. (kg equivalent in carbon dioxide)
Human toxicity, cancer effects	Comparative Toxic Unit for humans (CTUh)	CTUh (comparative toxic units for human)
Human toxicity, non-cancer effects	Comparative Toxic Unit for humans (CTUh)	CTUh (comparative toxic units for human)
Particulate matter /Respiratory inorganics	Intake fraction for fine particles	PM2.5-equiv. (kg equivalent of particulate matter with diameter under 2.5μm)
Photochemical ozone formation	Tropospheric ozone concentration increase	kg NMVOC equiv. (kg equivalent of non-methane volatile organic compounds)
Acidification	Accumulated Exceedance (AE)	Mole of H+ equiv. (equivalent molar concentration of the hydrogen ion)
Eutrophication, terrestrial	Accumulated Exceedance (AE)	Mole of N equiv. (equivalent molar concentration of the nitrogen atom)
Eutrophication, aquatic	Fraction of nutrients reaching freshwater end compartment (P) or marine end compartment (N)	kg P equiv. (kg phosphorus equivalent)
Ecotoxicity (fresh water)	Comparative Toxic Unit for ecosystems (CTUe)	CTUe (comparative toxic units for ecosystem)

4.3.2. Characterization

4.3.2.1. Climate Change Potential

The climate change potential (CCP) of conventionally farmed rice is 1.01E+00 kg equivalents carbon dioxide (CO_2) per 1 kg of rice, which is a larger value than the CCP of environmentally-friendly rice. The low-pesticide rice CCP value is 7.01E-01 kg CO_2 equivalents per kg of rice, or 69.41% of the conventional rice CCP value. The non-pesticide rice CCP value is 5.37E-01 kg CO_2 equivalents per kg of rice, or 53.17% of conventional rice impact. The organic rice CCP value is 2.34E-01 kg CO_2 equivalents per 1 kg of rice, which is only 23.17% of conventional rice's impact.

Through the eco-labelling system of rice farming, the reduction of chemical fertilizers and organosysnthetic agricultural chemicals has a measurable effect on CCP. When cutting the amount of fertilizer and pesticide by half, as in the case of low-pesticide rice farming, the potential of aquatic eutrophication can be reduced 30.59%. Furthermore, decreasing the chemical fertilizer by 1/3 reduces 46.83% of aquatic eutrophication potential and using no agricultural chemicals (organic farming) reduces it by 76.83%.

Domestic, South Korean research about rice farming, particularly by Ryu et al. (2012), reports that the national average of carbon emissions of the top-down research method is 2.39E+00kg CO_2 equivalents. Case analysis of the bottom-up research method reports carbon emissions at

1.04E+00kg CO2 equivalent per 1 kg of conventional rice farming. The results of a case study are 103% higher than results of conventional rice in this study. In addition, Ryu et al.'s national average shows 237% higher carbon emissions than those of conventional rice in the present study. These differences may be attributed to variances in amounts of fertilizer, organosynthetic chemicals, and agri-materials and differences in yield production among crop seasons. Lower GHG emissions may be the result of lower crop yields and not related to the farming system. (Blengini and Busto, 2009; Hokazono and Hayashi, 2012).

Hokazono et al. (2009) evaluated the CCP of rice farming in Japan and found the following values: conventional rice is 1.5E+00kg CO_2-equivalents, sustainable rice is 1.3E+00kg CO_2 equivalents, and organic rice is 1.65E+00kg CO_2 equivalents. The differences consequence value of climate change with Korean rice farming in this study come from establishing difference system boundaries with Japanese rice farming research. According to difference of system boundaries, the CCP of Japanese rice is 149% higher than Korean conventional rice farming and 705% higher than Korean organic farming per 1 kg of rice.

When farming 1 kg of rice in Thailand, the potential of climate change is 2.93E+00kg CO_2 equivalents, as reported in Kasmaprapruet et al.'s (2009) study. The Thailand study's system boundary included transportation, drying, and milling, the resulting CCP was 290% higher than the current study's Korean conventional rice farming CCP.

Blengini and Busto (2009) established a system boundary for their study of rice produced in Vercelli, Italy, which included the milling

process and found the potential of climate change to be 2.9 kg CO_2-equivalents, which is 287% higher than 1 kg of Korean conventional rice farming.

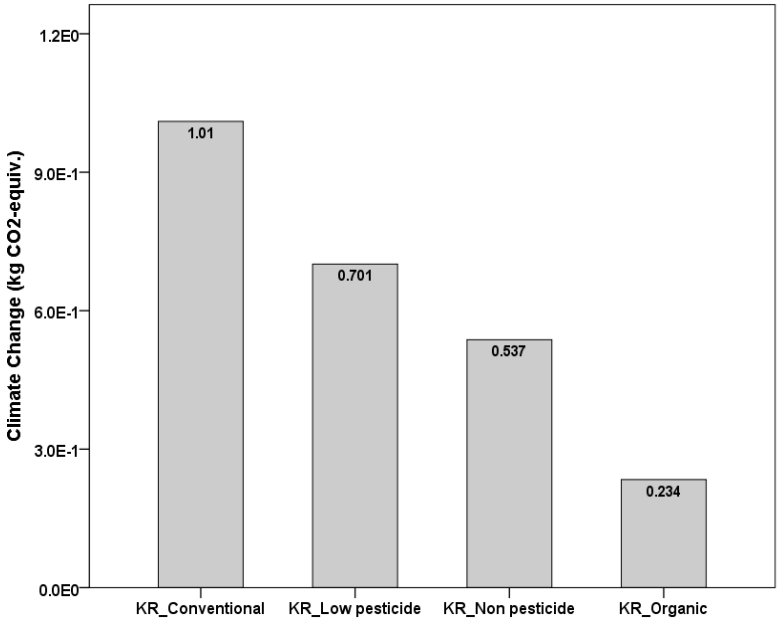


Figure 8 Climate Change Potential

4.3.2.2. Acidification Potential

The acidification potential (AP) of conventional rice has 6.33E-04 mole of hydrogen ion (H^+) equivalents per 1 kg of rice. This impact value is also the biggest value among rice farming systems. The low-pesticide rice AP value is 4.91E-04 mole of H^+ equivalents per kg of rice, or 77.57% of the conventional rice impact. The non-pesticide rice AP value is 68.72% of that of conventional rice, at 4.35E-04 mole of H^+ equivalents per 1 kg of rice. The organic rice AP value is 49.45% of the conventional rice AP impact, at 3.13E-04 mole of H^+ equivalents per 1 kg of rice.

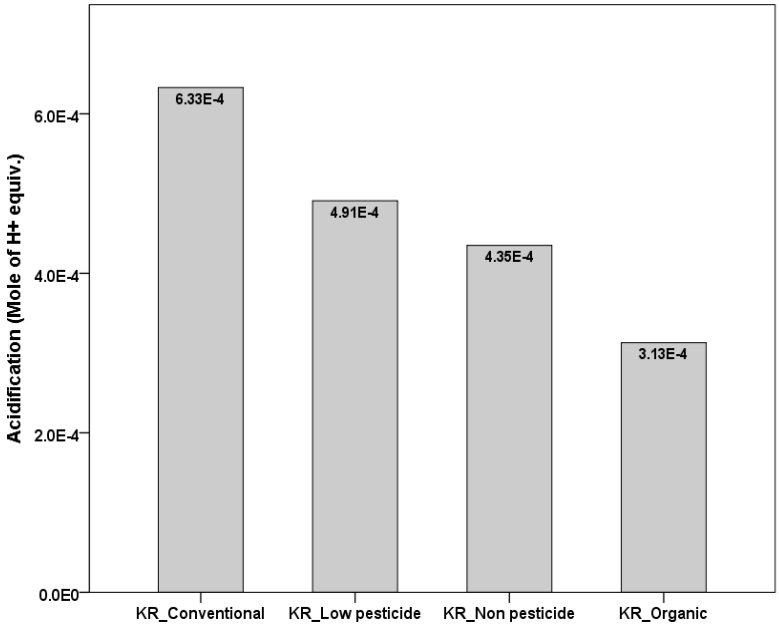


Figure 9 Acidification Potential

4.3.2.3 Eutrophication Potential

The eutrophication potential (EP) is divided into terrestrial and aquatic eutrophication. In terms of terrestrial eutrophication, conventional rice's EP value is 3.02E-03 mole of nitrogen (N) equivalents. The low-pesticide rice EP value is 2.48E-03 mole of N equivalents, which is 82.12% of conventional rice's impact. The non-pesticide rice EP value is 77.15% of that of conventional rice, which is 2.33E-03 mole of N equivalents. Finally, the organic rice EP value is 57.28% of that of conventional rice's impact, at 1.73E-03 mole of N equivalents.

As for aquatic eutrophication values, conventional rice measures at 6.03E-06 kg of phosphorus (P) equivalents. Low-pesticide rice measures at 3.02E-06 kg of P equivalents (50.08% of conventional). Non-pesticide rice yields 0.52% of conventional rice's value at is 3.13E-08 kg of P equivalents. Finally, organic rice measures at 0.11% of conventional rice's impact at 6.47E-09 kg of P equivalents.

Through the eco-labelling system of rice farming, the reduction of chemical fertilizers and organosysnthetic agricultural chemicals has a great effect on aquatic eutrophication potential. In the case of low-pesticide rice farming, when cutting the amount of fertilizer and pesticide by half, the potential of aquatic eutrophication can be reduced to 48.5% of that of conventional farming. Furthermore, aquatic eutrophication potential can be reduced by up to 99.9% when decreasing the chemical fertilizer to 1/3 of conventional methods or by eliminating agricultural chemicals.

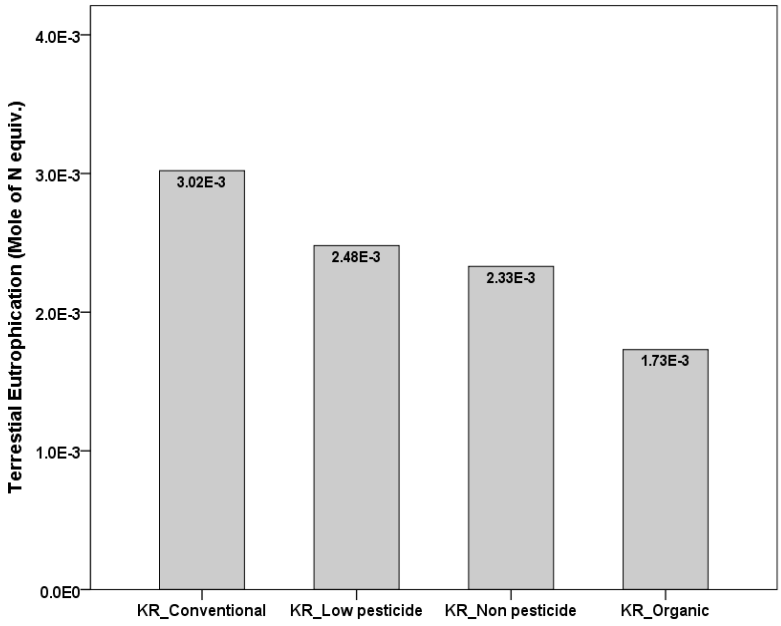


Figure 10 Terrestrial Eutrophication Potential

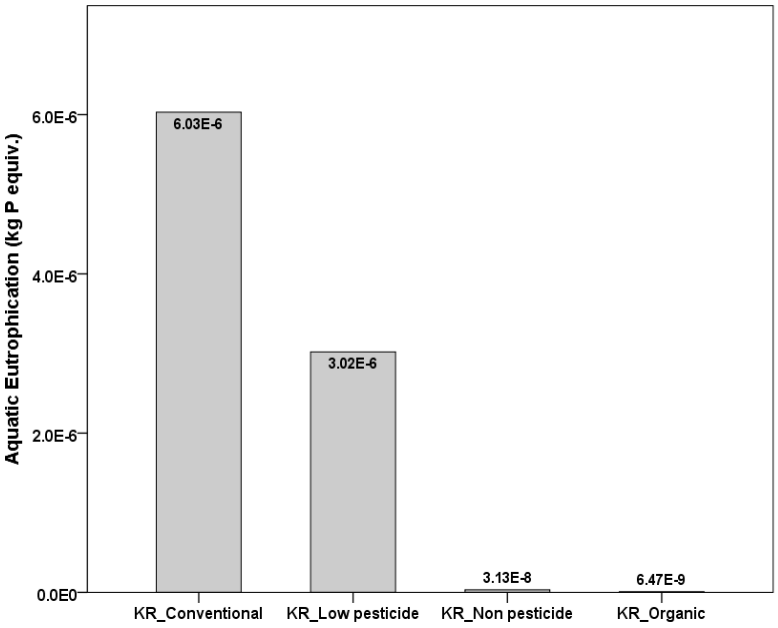


Figure 11 Aquatic Eutrophication Potential

4.3.2.4. Human Toxicity Potential

The human toxicity potential (HTP) is divided into cancerous toxicity and non-cancerous toxicity in humans. The cancerous human toxicity potential (HTP-C) of conventional rice has 8.02E-10 comparative toxic unit for humans (CTUh) per 1 kg of rice. This impact value is the highest of the rice farming systems. Low-pesticide rice's HTP-C value is 4.13E-10 CTUh per 1 kg of rice (51.50% of conventional). Non-pesticide rice's value is 45.26% that of conventional rice's impact at 3.63E-10 CTUh per 1 kg of rice. Organic rice's HTP-C value is 5.04% of conventional rice's impact at 4.04E-11 CTUh per 1 kg of rice.

The non-cancerous human toxicity potential (HTP-NC) of conventional rice is 1.19E-07 CTUh per 1 kg of rice. Low-pesticide rice's HTP-NC value is 1.03E-07 CTUh per 1 kg of rice, 86.55% that of conventional rice. Non-pesticide rice's HTP-NC value is 75.97% that of conventional rice at 9.04E-08 CTUh per 1 kg of rice. Organic rice's value is 61.09% that of conventional rice at 7.27E-08 CTUh per 1 kg of rice.

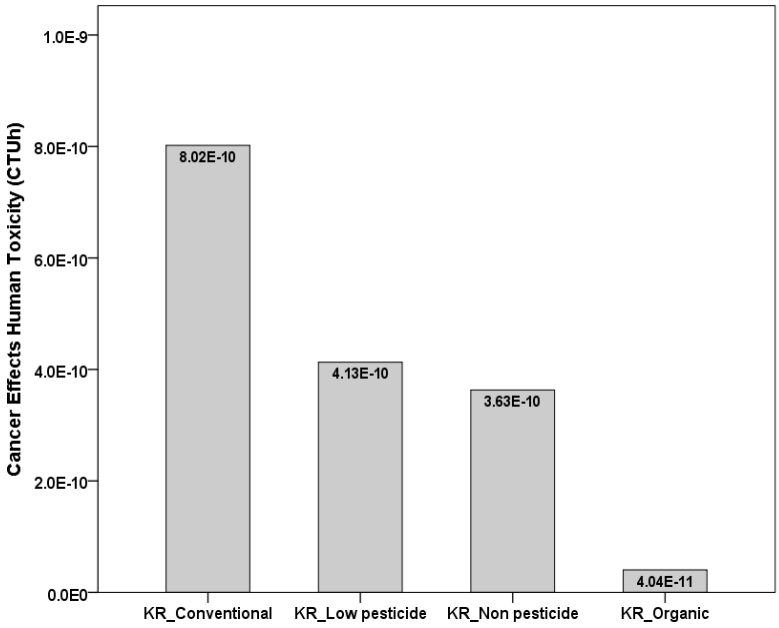


Figure 12 Cancerous Human Toxicity Potential

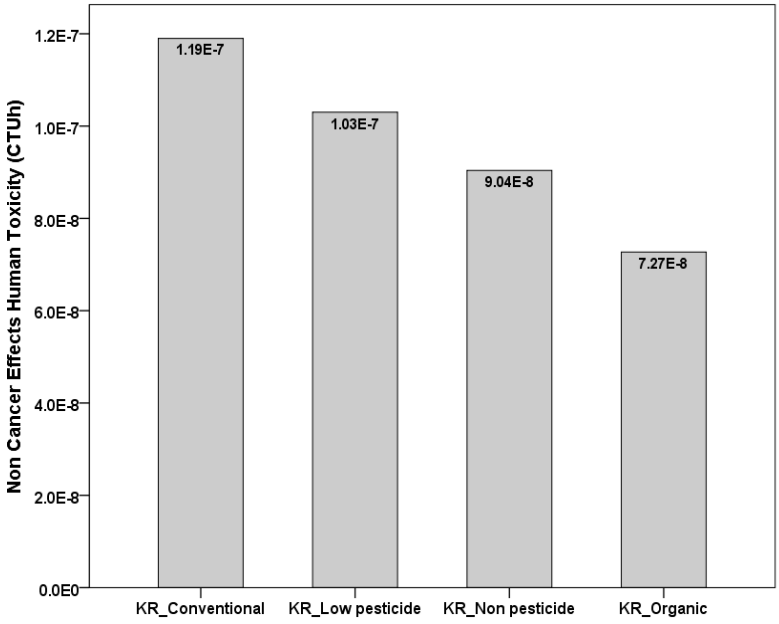


Figure 13 Non-cancerous Human Toxicity Potential

4.3.2.5 Particulate Matter Potential

The particulate matter potential (PMP) (also called "respiratory inorganics potential") of conventional rice farming is 7.28E-05 kg ultrafine particles (PM2.5) equivalents per 1 kg of rice. Low-pesticide rice's PMP value is 5.94E-05 kg PM2.5 equivalents per 1 kg of rice, or 81.59% that of conventional rice. Non-pesticide rice's PMP value is 5.54E-05 kg PM2.5 equivalents per 1 kg of rice, or 76.10% that of conventional rice. Organic rice's PMP impact is 4.10E-05 kg PM2.5 equivalents per kg of rice, which is 56.32% of conventional rice's impact.

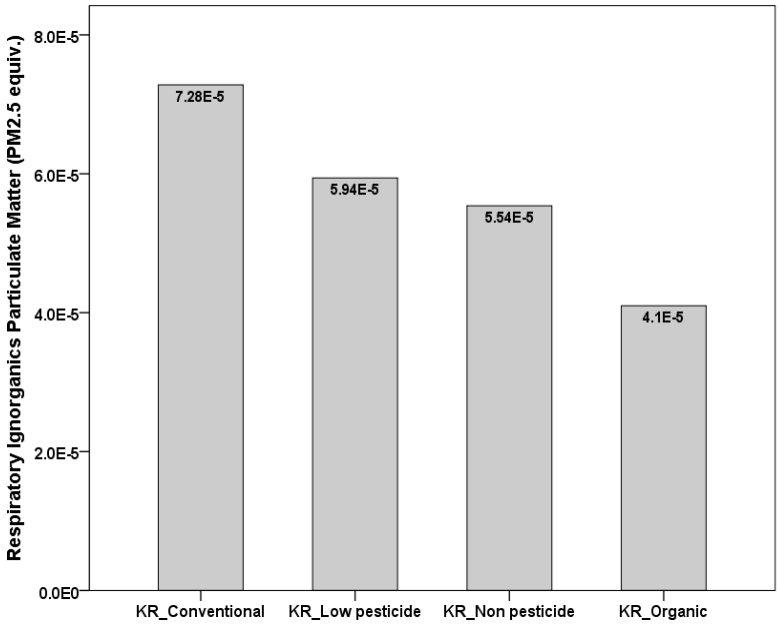


Figure 14 Particulate Matter (PM2.5) Potential

4.3.2.6 Photochemical Ozone Formation Potential

The photochemical ozone formation potential (POFP) of conventional rice is 6.38E-04 kg of non-methane volatile organic compound (NMVOC) equivalents. Low-pesticide rice's POFP value is 5.66E-04 kg NMOVOC equivalents (88.71% that of conventional rice); non-pesticide rice's POFP value is 5.21E-04 kg NMOVOC equivalents (or 81.66% that of conventional rice), and organic rice's POFP value is 4.44E-04 kg NMOVOC equivalents (69.59% that of conventional rice).

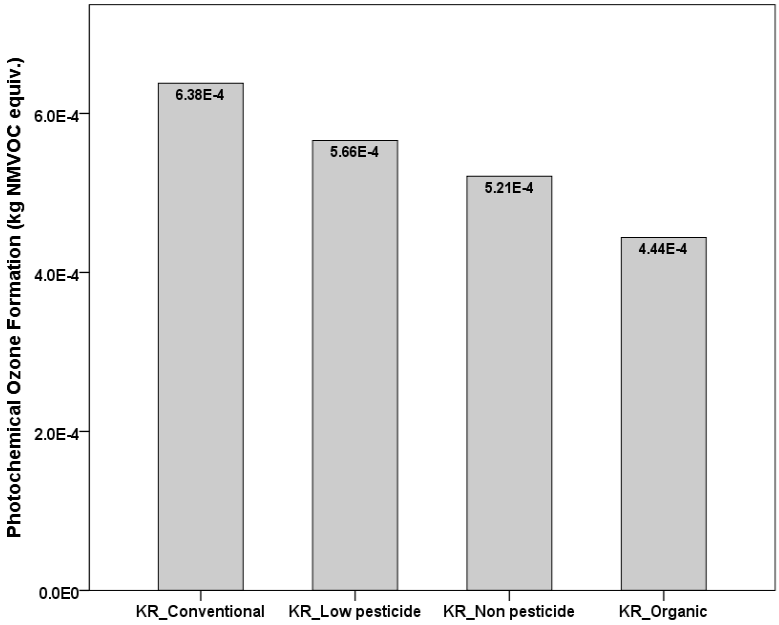


Figure 15 Photochemical Ozone Formation Potential

4.3.2.7 Freshwater Aquatic Ecotoxicity Potential

The freshwater aquatic ecotoxicity potential (FAEP) of conventional rice has 1.11E-01 comparative toxic unit for ecosystems (CTUe) per 1 kg of rice. The potential of low-pesticide rice is 7.70E-02 CTUe (69.37% of conventional), non-pesticide rice is 5.18E-02 CTUe (46.67% of conventional), and organic rice is 3.63E-02 CTUe, (32.70% of conventional rice).

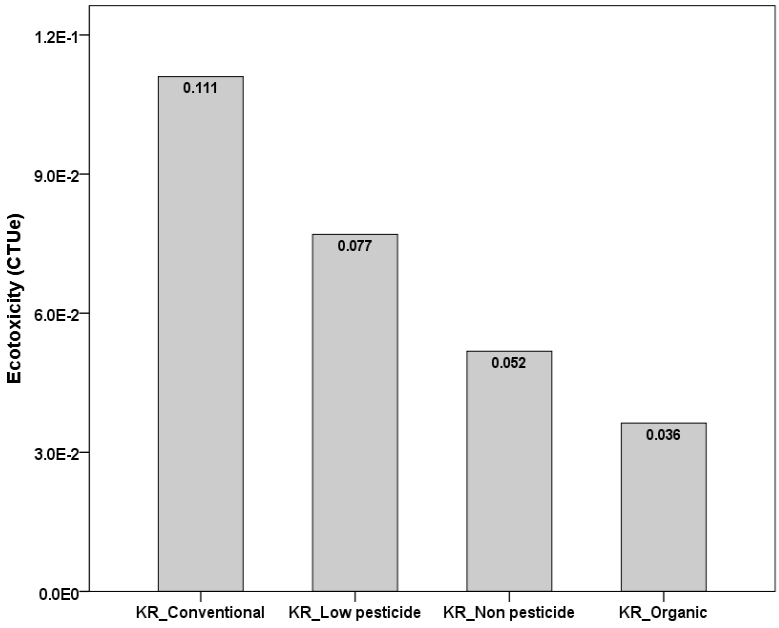


Figure 16 Freshwater Aquatic Ecotoxicity Potential

4.3.3. Normalization

Environmental indicators may be evaluated according to and using data from each environmental impact category. However, these indicators have limitations in that the quantitative assessment of the practical emissions is difficult. For this reason, normalization is employed to quantitatively evaluate how rice farming systems affect the amount of emissions created on a global, per person or specific area scale. Normalization allows comparisons of environmental indicators between impact categories.

Data on the environmental load of the reference area is necessary to accurately attribute the environmental load to the impact categories. However, in the case of South Korea, as pollutant emissions are announced only to some pollutants in several organizations such as the Environment Department, it is impossible to evaluate the total environmental impact of domestic activity (Chung et al., 1997). As accurate information was lacking from South Korea, the present study instead used figures derived from 27 E.U. countries, provided by ILCD Recommendations (Figure 17).

As an example, the climate change potential of 1.01 to 0.224 kg CO_2 equivalents resulting from the production of 1 kg of rice may be analyzed on its face as having a relatively large influence on the environment. However, normalization may show that it is, in reality, a significantly small value of about 1.0E−13. In another example, freshwater aquatic ecotoxicity potential was analyzed, the results ranging

from 0.111 to 0.036 CTUe depending on the farming system, but as a result of normalization, it was revealed that the annual environmental impact in Europe was a smaller value of 1.0E-14.

Among the 9 environmental impact categories, non-cancerous human toxicity was analyzed as having the greatest influence. Production of 1 kg of conventional farming has contributed to about 4.47E-13 of all non-cancerous human toxicity occurring in European countries. The low-pesticide rice rate is 3.87E-13; the non-pesticide rice rate is 3.40E-13, and the organic farming rate is 2.73E-13.

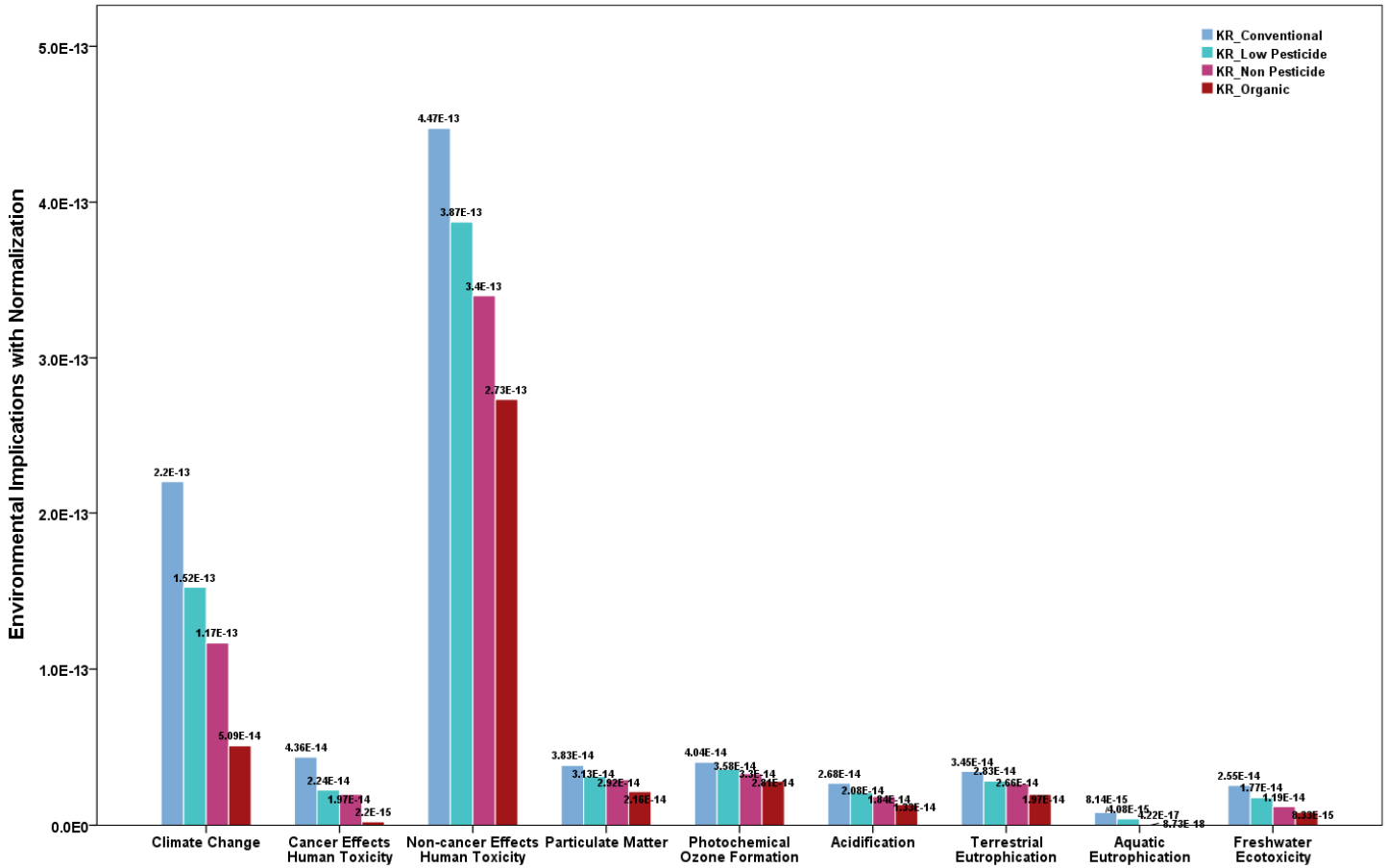


Figure 17 Normalized Environmental Implications of Rice Farming Systems in South Korea

4.3.4. Weighting

Weighting is a process that determines the rank of the results of characterization or normalization indicators. The ratio of each indicator is set by analyzing indicators divided by a standardized weight. The relative environmental influences of the production of Korean environmentally-friendly rice are the same as below, when the value of those of conventional farming is set at 100. The influences of each farming system are expressed in proportion to that value (Noh et al., 1997).

Conventional farming is ranked first, followed by low-pesticide farming (73.73), non-pesticide farming (59.57), and organic farming (34.31). (See Figure 18.)

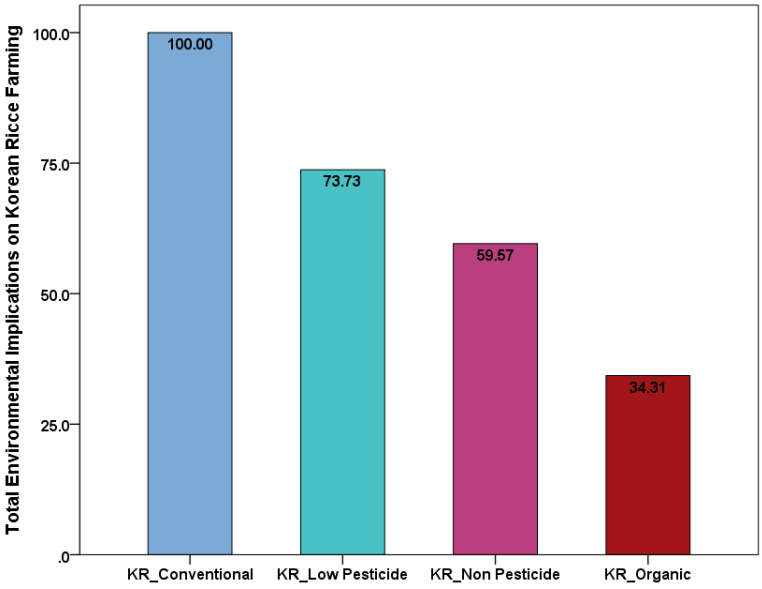


Figure 18 Environmental Implications of Korean Rice Farming

Table 12 Environmental Implications of Korean Rice Farming with Weighting

Impact Category	Conventional	Low Pesticide	Non Pesticide	Organic
Climate change	5.05.E-12	3.51.E-12	2.69.E-12	1.17.E-12
Human Toxicity, cancer effects	2.62.E-13	1.35.E-13	1.18.E-13	1.32.E-14
Human Toxicity, non-cancer effects	1.79.E-12	1.55.E-12	1.36.E-12	1.09.E-12
Particulate matter/Respiratory inorganics	2.68.E-13	2.19.E-13	2.04.E-13	1.51.E-13
Photochemical Ozone formation	2.02.E-13	1.79.E-13	1.65.E-13	1.41.E-13
Acidification	1.07.E-13	8.32.E-14	7.37.E-14	5.31.E-14
Eutrophication, terrestial	1.21.E-13	9.91.E-14	9.31.E-14	6.91.E-14
Eutrophication, aquatic	2.85.E-14	1.43.E-14	1.48.E-16	3.06.E-17
Ecotoxicity	2.80.E-13	1.94.E-13	1.31.E-13	9.16.E-14
Total (%)	8.11.E-12 (100.00)	5.98.E-12 (73.73)	4.83.E-12 (59.57)	2.78.E-12 (34.31)

4.4 Interpretation of Korean Rice Farming Systems

4.4.1 Sensitivity Analysis of Direct Field Greenhouse Gas (GHG) Emissions

The agricultural sector is a greenhouse gas source that accounts for about 10-20% of global GHG emissions (Smith et al., 2007; Lehugera et al., 2011). The major factors of GHG emissions in agriculture can be divided into direct emissions and indirect emissions. Direct emissions mean emissions through land use during crop cultivation. Indirect emissions include GHG emissions from the production of inputs such as fertilizers and pesticides, and fuel combustion from agricultural machinery. However, this study did not consider the direct field emission from land use in the rice growing process. Only indirect emissions from farming materials and energy input were considered since the certificate system is operated based on the amount of agricultural materials used when cultivating crops due to the nature of the environmentally friendly agricultural products certification system.

Methane emissions from rice field cultivation using direct field emissions of fresh water were estimated using the agricultural sector GHG emissions formula presented in the 2006 IPCC Guidelines. To calculate the amount of greenhouse gas emissions, the Tier 1 value of IPCC 1996/2006 was applied to the rice cultivation area, and it was calculated using the organic fertilizer application, the presence of fresh water, the number of cultivation days, and the number of days of fresh

water.

Thanawong et al. (2014) reported about 2.84 to 3.45 kg of CO_2-equivalent in 1 kg of rice grown in rain-fed and 4.51 to 5.12 kg of CO_2-equivalent in wet-season irrigated rice, respectively. Direct field emissions (greenhouse gas) accounted for the following percentages: 61.88%in rain-fed paddy rice, 27.29% in field operations, 8.68% in fertilizers including manufacturing and transport, 0.02% in pesticides, and 2.13% in rice seed production. In other words, in the case of wet-season irrigated rice, about 2.79-3.17 kg CO_2-equivalent at 4.51-5.12 kg CO_2-equivalent is the carbon dioxide equivalent generated during the rice growing process.

Brodt et al. (2014) evaluated GHG and CO_2-equivalent emissions for baseline rice production processes. The annual field emissions of direct GHG emissions were 1.02 kg CO_2-equivalents per kg of rice, which accounts for 64.1% of the total CO_2-equivalents emissions. Regarding indirect emissions for rice farming (including land preparation, fertilizer production and application, seed production and seeding, pest management, harvest and straw management, transportation, and the drying and milling process), 0.57 kg CO_2-equivalents were emitted in indirect field emissions. For comparison, Blengini and Busto (2009) evaluated GWP for Italy rice farming, and found that indirect and direct field emissions were about 32% and 68%, representatively, among the total GHG emissions (1.59 kg CO_2-equivalents per kg of rice)

Previous research has also estimated the ratio of indirect GHG emission for the direct emissions. The direct emissions can be 1.64-1.97

Table 13 Comparison of Direct Field Emissions Estimation

Comparison		Greenhouse Gas Emissions (kg CO_2-equivalents per kg rice)		
		Total	Direct	Indirect
Thanawong et al. (2014)		4.51~5.12 (100.0%)	2.79~3.17 (61.9%)	1.72~1.95 (38.1%)
Brodt et al. (2014)		1.59 (100.0%)	1.02 (64.1%)	0.57 (35.9%)
Blengini and Busto (2009)		2.90 (100.0%)	1.97 (68.0%)	0.93 (32.0%)
Current study	Conventional	2.65~2.98	1.64~1.97 (61.9~68.0%)	1.01
	Low Pesticide	2.34~2.67		0.70
	Non Pesticide	2.18~2.51		0.54
	Organic	1.87~2.20		0.23

as it accounts for about 61.9% to 68.0% of the total GHG emissions. Conventional rice farming produces about 2.65-2.98kg CO_2-equivalents of rice 1kg. The GHG reduction effects of low-pesticide farming is about 11-13% GHG reduction compared to conventional farming, non-pesticide is about 18-21%, and organic farming is about 35~42%.

4.4.2 Sensitivity Analysis of Databases Difference for Agricultural Materials

The Ecoinvent database has been used for the life-cycle inventory of agricultural materials such as fertilizers, organosynthesis pesticides, and energy in South Korea to evaluate environmental implications on rice farming systems in South Korea. It was carried out under the assumption that the production of agricultural materials like fertilizer and pesticide in Europe and Korea is the same. However, the environmental impacts on farming materials may vary depending on country characteristics, so the existing US and European databases were compared to determine if these databases have difference by country.

This study conducted a comparative analysis to evaluate how the environmental impacts of the Ecoinvent and US LCI databases differ for the same process. Energy and fertilizer, an important process in the eco-labelling system, were selected to compare these databases. Characterization, normalization, and weighting were performed on the same proceedings as in the previous environmental impact methods for same process including N fertilizer and diesel.

Since N fertilizer is the most commonly used fertilizer in rice cultivation, it was selected as the environmental impact comparison for fertilizer. 1kg of N fertilizer provided in the US LCI database was considered, but N fertilizer in the Ecoinvent database is divided into urea, ammonium sulfate, ammonium nitrate, and ammonium phosphorus. In Ryu et al. (2012), urea and ammonium sulfate were

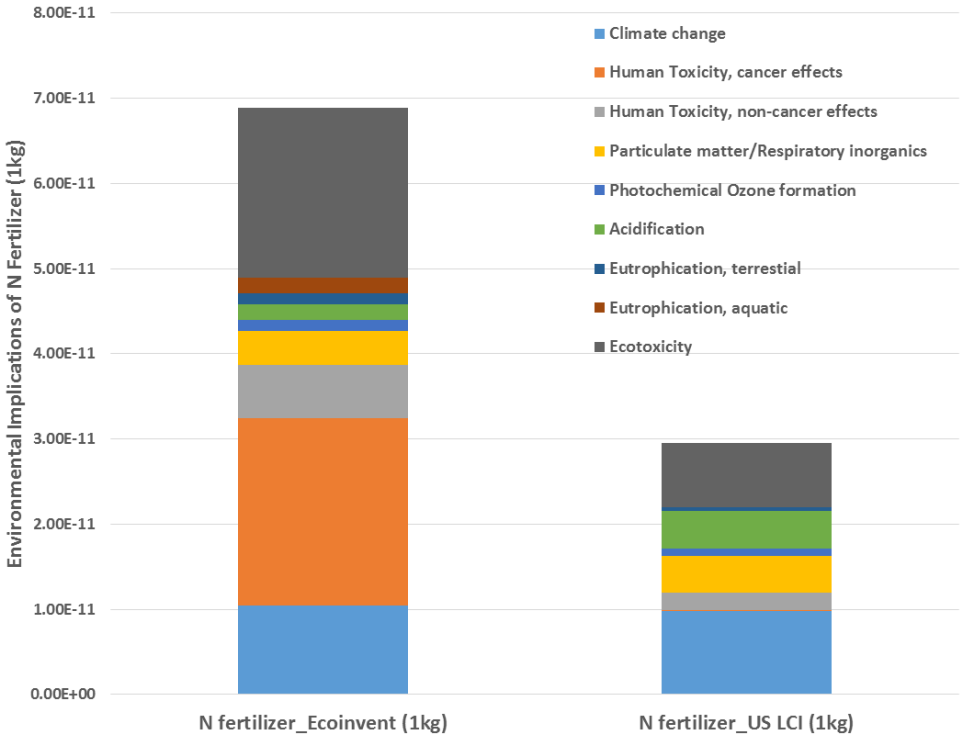


Figure 19 Environmental Implications of N Fertilizer (1kg) according to Ecoinvent and US LCI Databases

used for N fertilizer used in Korea. Therefore, urea and ammonium sulfate were considered in the current study for the N fertilizer provided by Ecoinvent. Since these two fertilizers have different nitrogen content, they were assigned 46% for the urea and 21% for the ammonium sulfate after evaluating the environmental impact for each 1 kg.

For the weighting results comparing N fertilizer 1kg in US LCI and Ecoinvent databases, the environmental impact of N fertilizer in the Ecoinvent database (6.88E−11) was estimated to be about 2.33 times higher than those of the US LCI (2.95E−11) (Figure 19). In most

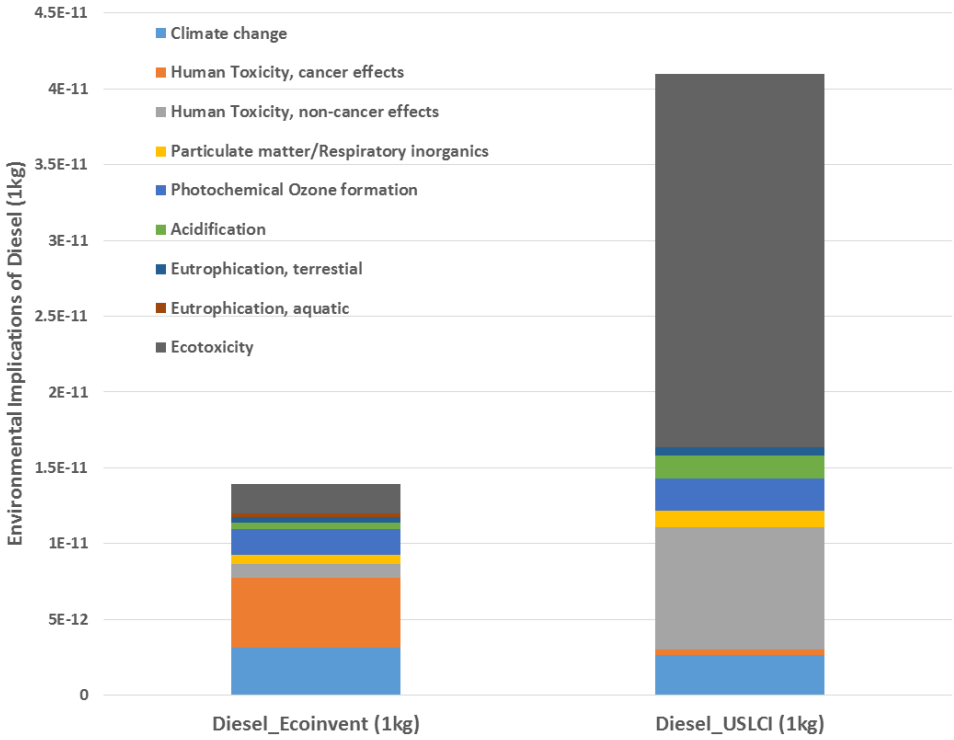


Figure 20 Environmental Implications of Diesel (1kg) according to Ecoinvent and US LCI Databases

categories including climate change potential, the Ecoinvent database was found to be about 106% to 349% higher than the US LCI database. Specifically, the cancerous human toxicity potential was analyzed at 154 times higher than the Ecoinvent database. In contrast, the particulate matter potential and acidification potential were 93% and 41% higher in the US LCI database than in the Ecoinvent, respectively.

Unlike fertilizer, the environmental impact of 1kg diesel based on the US LCI database (4.10E−11) was about 2.94 times higher than that of

the Ecoinvent database (1.39E-11) (Figure 20). The US LCI values were higher than the Ecoinvent values in most environmental impact categories, except for climate change potential and cancerous human toxicity potential. In particular, non-cancerous human toxicity was about 896% higher than that of Ecoinvent, with a US LCI value of 8.06E-12. Similarly, the acidification potential was also about 338% higher for US LCI. In contrast, climate change and cancerous human toxicity were 85% and 7% higher in the US LCI database than in Ecoinvent, respectively.

Given the different characteristics of the countries in which the databases were constructed, the environmental impact can vary greatly. It is assumed that the production of European and Korean production equipment is the same, but more accurate results can be evaluated by using the unique life-cycle database reflecting the characteristics of Korea. These results suggest that Korea needs to build a life-cycle inventory of all its agricultural materials, including fertilizers and pesticides.

CHAPTER 5. LIFE-CYCLE ENVIRONMENTAL IMPLICATIONS OF RICE FARMING

An LCA of eco-labelling of rice farming systems in the U.S. and Europe was also conducted according to international standards of the environmental evaluation of products, particularly the ISO 14040 series, established by the International Organization for Standardization (ISO).

5.1. LCA of Rice Farming Systems in the United States and Europe

5.1.1. Goal and Scope Definition

The goal of this section is to compare the environmental implications of conventional rice farming in the United States and Europe to eco-labelling of Korean rice farming. The United States LCI database, created by the National Renewable Energy Laboratory (NREL), was used in the present study to evaluate U.S. conventional rice farming. For conventional rice farming in Europe, the Ecoinvent inventory database, created by the Ecoinvent Centre (also known as the Swiss Centre for Life Cycle Inventories), was used.

For the comparison, 1 kg of paddy rice, unpackaged, at the farm exit gate, was chosen as the functional unit for all three data sets (U.S., E.U., and South Korea).

The system boundary was established using a cradle-to-farm gate (CtG) perspective. The agricultural system for conventional farming in the U.S. and Europe is different than in Korean rice farming. The U.S. and Europe system consists of germinating the seed, preparing the land, sowing, cultivating and managing, and harvesting. The system boundaries for rice farming systems in the U.S. and Europe are illustrated in Figure 19.

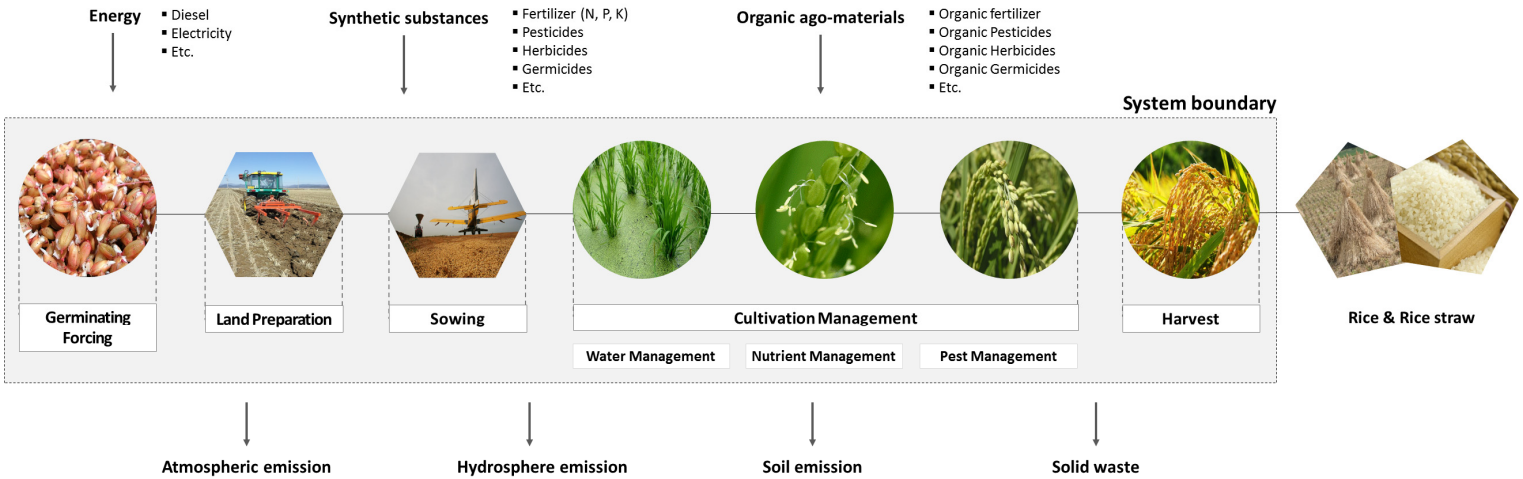


Figure 21 System Boundary of Rice Production in the US and Europe: Cradle-to-Farm Gate Perspective

5.1.2. LCI Analysis

The environmental implications of rice farming systems in U.S. and Europe were analyzed using the U.S. LCI database provided by NREL for U.S. figures and the Ecoinvent database for European figures. Ecoinvent is a systematically and diversely established database of agricultural products, covering all agriculture and stockbreeding matters, including agricultural products, agricultural infrastructures, agri-materials, and farm machinery. This database provides more detail about fertilizer, pesticide, and agricultural work process as compared to the U.S. LCI database. The processes of irrigation, transportation, and drying were excluded by the set system boundary.

According to the U.S. LCI, electricity, diesel, liquefied petroleum gas, and natural gas are used as energy in producing rice in the U.S.. Lime, nitrogen fertilizer, phosphorous, and potash as a dummy variable of the fertilizer make up the 4.03E-02kg of fertilizers used in the production of 1 kg of rice. The other dummy variables are agrochemical and copper.

According to Ecoinvent, pesticide, work process, fertilizer, and inorganics are all used in European rice production. The total amounts of pesticide used to produce 1 kg of rice are 5.62E-04kg; fertilizer is 1.93E-02kg. The Ecoinvent database lists work process for agriculture inventory in terms of usable area, rather than energy consumption as in the U.S. LCI.

Table 14 Life-cycle Inventories for 1 kg from U.S. LCI Database

	Flow	Amount	Unit
Input	Electricity [Electric power]	1.80.E-01	MJ
	Lime quicklime (lumpy) [Minerals]	6.89.E-03	kg
	US: Diesel, combusted in industrial equipment [Products and Intermediates]	4.86.E-05	m^3
	US: Liquefied petroleum gas, combusted in industrial boiler [Products and Intermediates]	2.83.E-06	m^3
	US: Natural gas, combusted in industrial boiler [Products and Intermediates]	5.37.E-03	m^3
	US: Nitrogen fertilizer, production mix, at plant [Products and Intermediates]	2.38.E-02	kg
	US: Transport, single unit truck, diesel powered [Products and Intermediates]	1.63.E+01	kgkm
	US: Transport, train, diesel powered [Products and Intermediates]	3.99.E+01	kgkm
	US: Dummy_Agrochemicals, at plant [Dummy Flows]	9.21.E-04	kg
	US: Dummy_Copper, at regional storage [Dummy Flows]	1.61.E-04	kg
	US: Dummy_Phosphorous Fertilizer (TSP as P2O5), at plant [Dummy Flows]	5.17.E-03	kg
	US: Dummy_Potash Fertilizer (K2O), at plant [Dummy Flows]	4.48.E-03	kg
	Carbon dioxide [Renewable resources]	-1.27.E+00	kg
	Occupation, arable, conservation tillage [Hemeroby]	9.23.E-02	sqm
	Occupation, arable, conventional tillage [Hemeroby]	1.32.E+00	sqm
	Occupation, arable, reduced tillage [Hemeroby]	1.23.E-01	sqm
	Water (river water) [Water]	4.22.E+02	kg

	Water (well water) [Water]	2.46.E+02	kg
Output	US: Rice grain, at field [Products and Intermediates]	1.00.E+00	kg
	US: Rice straw, at field [Products and Intermediates]	1.22.E+00	kg
	2,4-Dichlorophenoxyacetic acid (2,4-D) [Pesticides to air]	9.51.E-06	kg
	2,4-Dichlorophenoxyacetic acid (2,4-D) [Pesticides to fresh water]	4.08.E-07	kg
	Ammonia [Inorganic emissions to air]	1.43.E-03	kg
	Bentazone [Pesticides to air]	2.47.E-06	kg
	Bentazone [Pesticides to fresh water]	1.06.E-07	kg
	Carbaryl [Pesticides to fresh water]	6.88.E-08	kg
	Carbaryl [Pesticides to air]	1.60.E-06	kg
	Carbofuran [Pesticides to air]	5.48.E-06	kg
	Carbofuran [Pesticides to fresh water]	2.35.E-07	kg
	Carbon monoxide [Inorganic emissions to air]	7.22.E-03	kg
	Copper (+II) [Heavy metals to fresh water]	2.41.E-06	kg
	Glyphosate [Pesticides to air]	4.75.E-06	kg
	Glyphosate [Pesticides to fresh water]	2.03.E-07	kg
	Hydrocarbons (unspecified) [Organic emissions to air (group VOC)]	5.53.E-04	kg
	Malathion [Pesticides to fresh water]	1.11.E-07	kg
	Malathion [Pesticides to air]	2.60.E-06	kg
	MCPA [Pesticides to air]	2.44.E-06	kg

MCPA [Pesticides to fresh water]	1.05.E-07	kg
Methane [Organic emissions to air (group VOC)]	4.46.E-02	kg
Molinate [Pesticides to air]	7.08.E-05	kg
Molinate [Pesticides to fresh water]	3.04.E-06	kg
Nitrogen (as total N) [Inorganic emissions to fresh water]	2.90.E-03	kg
Nitrogen oxides [Inorganic emissions to air]	4.26.E-03	kg
Nitrous oxide (laughing gas) [Inorganic emissions to air]	7.43.E-04	kg
Paraquat [Pesticides to fresh water]	6.13.E-09	kg
Paraquat [Pesticides to air]	1.43.E-07	kg
Parathion-methyl [Pesticides to air]	3.93.E-06	kg
Parathion-methyl [Pesticides to fresh water]	1.68.E-07	kg
Pendimethalin [Pesticides to air]	1.11.E-05	kg
Pendimethalin [Pesticides to fresh water]	4.76.E-07	kg
Phosphorus [Inorganic emissions to fresh water]	3.05.E-05	kg
Propanil [Pesticides to air]	1.55.E-04	kg
Propanil [Pesticides to fresh water]	6.65.E-06	kg
Solids (suspended) [Particles to fresh water]	1.07.E+00	kg
Thiobencarb [Pesticides to air]	3.71.E-05	kg
Thiobencarb [Pesticides to fresh water]	1.59.E-06	kg

Table 15 Life-cycle Inventories for 1 kg from Ecoinvent Database

	Flow	Amount	Unit
Input	CH: [sulfonyl]urea-compounds, at regional storehouse [Pesticide]	3.51.E-07	kg
	CH: [thio]carbamate-compounds, at regional storehouse [Pesticide]	1.66.E-04	kg
	CH: acetamide-anillide-compounds, at regional storehouse [Pesticide]	2.73.E-04	kg
	CH: application of plant protection products, by field sprayer [work processes]	9.48.E+00	sqm
	CH: benzo[thia]diazole-compounds, at regional storehouse [Pesticide]	3.98.E-06	kg
	CH: bipyridylium-compounds, at regional storehouse [Pesticide]	1.79.E-07	kg
	CH: combine harvesting [work processes]	1.45.E+00	sqm
	CH: cyclic N-compounds, at regional storehouse [Pesticide]	1.96.E-05	kg
	CH: dinitroaniline-compounds, at regional storehouse [Pesticide]	9.68.E-06	kg
	CH: fertilising, by broadcaster [work processes]	4.38.E+00	sqm
	CH: glyphosate, at regional storehouse [Pesticide]	1.42.E-05	kg
	CH: grain drying, low temperature [work processes]	1.30.E-01	kg
	CH: MCPA, at regional storehouse [Pesticide]	4.95.E-07	kg
	CH: organophosphorus-compounds, at regional storehouse [Pesticide]	1.32.E-05	kg
	CH: pesticide unspecified, at regional storehouse [Pesticide]	3.53.E-05	kg

CH: phenoxy-compounds, at regional storehouse [Pesticide]	2.57.E-05	kg
CH: sowing [work processes]	1.63.E+00	sqm
CH: tillage, cultivating, chiselling [work processes]	1.46.E+00	sqm
CH: tillage, harrowing, by spring tine harrow [work processes]	7.29.E+00	sqm
CH: tillage, ploughing [work processes]	2.92.E-01	sqm
CH: tillage, rolling [work processes]	1.46.E+00	sqm
RER: ammonia, liquid, at regional storehouse [inorganics]	1.14.E-02	kg
RER: ammonium nitrate, as N, at regional storehouse [mineral fertiliser]	5.47.E-03	kg
RER: diammonium phosphate, as N, at regional storehouse [mineral fertiliser]	1.71.E-03	kg
RER: diammonium phosphate, as P_2O_5, at regional storehouse [mineral fertiliser]	4.38.E-03	kg
RER: potassium chloride, as K2O, at regional storehouse [mineral fertiliser]	3.79.E-03	kg
RER: transport, lorry >16t, fleet average [Street]	4.80.E-03	tkm
RER: urea, as N, at regional storehouse [organics]	3.96.E-03	kg
US: irrigating [work processes]	1.08.E+00	m3
US: rice seed, at regional storehouse [seed]	2.06.E-02	kg
Carbon dioxide [Renewable resources]	1.46.E+00	kg
Energy, calorific value, in organic substance [Renewable energy resources]	1.63.E+01	MJ
Occupation, arable [Hemerobie Ecoinvent]	1.46.E+00	m2*yr

	Transformation, from arable [Hemerobie Ecoinvent]	1.46.E+00	sqm
	Transformation, to arable [Hemerobie Ecoinvent]	1.46.E+00	sqm
Output	US: rice, at farm [plant production]	1.00.E+00	kg
	2,4-Dichlorophenoxyacetic acid (2,4-D) [Pesticides to agricultural soil]	1.84.E-05	kg
	Ammonia [Inorganic emissions to air]	1.47.E-03	kg
	Azoxystrobin [Organic emissions to agricultural soil]	3.54.E-06	kg
	Bensulfuron methyl ester [Pesticides to agricultural soil]	1.24.E-06	kg
	Bentazone [Pesticides to agricultural soil]	3.98.E-06	kg
	Cadmium (+II) [Heavy metals to fresh water]	1.34.E-07	kg
	Cadmium (+II) [Heavy metals to agricultural soil]	9.57.E-08	kg
	Carbaryl [Pesticides to agricultural soil]	1.31.E-06	kg
	Carbofuran [Pesticides to agricultural soil]	1.20.E-06	kg
	Carbon dioxide [Inorganic emissions to air]	6.22.E-03	kg
	Chromium (+VI) [Heavy metals to fresh water]	1.76.E-05	kg
	Chromium (unspecified) [Heavy metals to agricultural soil]	-1.40.E-05	kg
	Copper (+II) [Heavy metals to fresh water]	1.12.E-05	kg
	Copper (+II) [Heavy metals to agricultural soil]	2.20.E-05	kg
	Dimethazone [Pesticides to agricultural soil]	1.87.E-05	kg

Fenoxaprop [Pesticides to agricultural soil]	7.81.E-08	kg
Glyphosate [Pesticides to agricultural soil]	1.42.E-05	kg
Halosulfuron-methyl [Pesticides to agricultural soil]	3.51.E-07	kg
Lambda cyhalothrin [Pesticides to agricultural soil]	5.08.E-07	kg
Lead (+II) [Heavy metals to fresh water]	1.84.E-06	kg
Lead (+II) [Heavy metals to agricultural soil]	-1.45.E-06	kg
Malathion [Pesticides to agricultural soil]	1.85.E-07	kg
MCPA [Pesticides to agricultural soil]	4.95.E-07	kg
Mecoprop [Pesticides to agricultural soil]	9.37.E-07	kg
Mercury (+II) [Heavy metals to fresh water]	1.27.E-09	kg
Mercury (+II) [Heavy metals to agricultural soil]	-1.37.E-09	kg
Methane (biotic) [Organic emissions to air (group VOC)]	4.07.E-02	kg
Molinate [Pesticides to agricultural soil]	1.05.E-04	kg
Nickel (+II) [Heavy metals to fresh water]	9.47.E-06	kg
Nickel (+II) [Heavy metals to agricultural soil]	-8.48.E-06	kg
Nitrate [Inorganic emissions to fresh water]	7.44.E-03	kg
Nitrogen oxides [Inorganic emissions to air]	1.20.E-04	kg
Nitrous oxide (laughing gas) [Inorganic emissions to air]	5.69.E-04	kg
Paraquat [Pesticides to agricultural soil]	1.79.E-07	kg

Parathion-ethyl [Pesticides to agricultural soil]	1.30.E-05	kg
Pendimethalin [Pesticides to agricultural soil]	9.68.E-06	kg
Phosphate [Inorganic emissions to fresh water]	2.15.E-04	kg
Phosphorus [Inorganic emissions to fresh water]	1.52.E-04	kg
Propanil [Pesticides to agricultural soil]	2.73.E-04	kg
Propiconazole [Pesticides to agricultural soil]	8.20.E-07	kg
Quinclorac [Pesticides to agricultural soil]	4.55.E-06	kg
Sodium chlorate [Inorganic emissions to air]	3.51.E-06	kg
Thiobencarb [Pesticides to agricultural soil]	5.84.E-05	kg
Triclopyr [Pesticides to agricultural soil]	6.32.E-06	kg
Zinc (+II) [Heavy metals to fresh water]	1.44.E-05	kg
Zinc (+II) [Heavy metals to agricultural soil]	-1.57.E-05	kg

5.1.3. LCIA

The environmental implications of conventional rice farming in the U.S. and Europe are shown Table 16. All characterized impact indicators of U.S. rice farming, except for cancerous human toxicity potential, had higher values than those of European conventional rice farming.

The impacts of climate change are 1.14E+00 kg carbon dioxide (CO_2) equivalents per 1 kg of conventional rice in Europe and 1.62kg CO_2 equivalents in the United States.

Acidification potential rates were 8.50E-04 mole H^+ equivalents and 5.83E-03 mole H^+ equivalents for Europe and the U.S., respectively.
The eutrophication potential in Europe was 4.14E-03 mole N equivalents for terrestrial, and 1.47E-06 kg P equivalents for aquatic. U.S. results were 1.21E-02 mole N equivalents for terrestrial and 3.05E-05 kg P equivalents for aquatic.

The potential of cancerous human toxicity was measured at 1.04E+09 CTUh per 1 kg of conventional rice in Europe, while it was 6.28E-10 CTUh per 1 kg rice in the U.S. Non-cancerous human toxicity was measured at 1.12E-07 CTUh in Europe and 2.48E-07 CTUh in the U.S.

For 1 kg of conventional rice farming in Europe, the particulate matter rate was 9.25E-05 kg PM 2.5 equivalents and photochemical ozone formation was 9.89E-04 kg NMVOC equivalents. Ecotoxicity for aquatic fresh water was measured at 1.00E-01 CTUe.

Production of 1 kg of conventional rice in the U.S. resulted in 1.76E-04kg PM 2.5 equivalents in particulate matter potential and 4.32E-03 kg NMVOC equivalents in photochemical ozone formation potential. Ecotoxicity for aquatic fresh water was measured at 4.08E-01 CTUe.

Table 16 Environmental Implications based on the U.S. and Europe Databases

Impact category	Unit	Provided Database for Rice Farming	
		Ecoinvent (Europe)	U.S. LCI (U.S.A)
Climate change	kg CO_2 eq.	1.14E+00	1.62E+00
Human toxicity, cancer effects	CTUh	1.04E-09	6.28E-10
Human toxicity, non-cancer effects	CTUh	1.12E-07	2.48E-07
Acidification	mole H+ eq.	8.50E-04	5.83E-03
Particulate matter/ Respiratory inorganics	kg PM2.5 eq.	9.92E-05	1.76E-04
Ecotoxicity for aquatic fresh water	CTUe	1.00E-01	4.08E-01
Photochemical ozone formation	kg NMVOC eq.	9.89E-04	4.32E-03
Eutrophication, terrestrial	mole N eq.	4.14E-03	1.21E-02
Eutorphication, aquatic	kg P eq.	1.47E-06	3.05E-05

5.2. National Comparison of Total Environmental Implications on Rice Farming

5.2.1. National Comparison by Characterized Indicators

The potential impact on climate change of the production of 1 kg of conventionally farmed rice was largest in the United States (Figure 20), at 1.62 kg CO_2 equivalents, compared to 1.14 kg CO_2 equivalents in Europe and 1.01 kg CO_2 equivalents in South Korea. The European climate change potential was about 29.63% lower and the Korean rice was 62.35% lower than the impact potential in the U.S. The U.S. impact from conventional farming was about 684% higher than the Korean organic rice impact and about 487% higher than the European conventional rice impact.

Regarding acidification potential, the US conventional rice rates were about 10 times higher than other conventional rice (Figure 21). Europe's rice farming impact value was 8.50E-04 mole of H^+ equivalent. Korea's was 6.33E-04 mole of H^+ equivalent. However, the U.S. impact value was 5.83E-03 mole of H^+ equivalent, which is 686% higher than that of rice in Europe and 921% higher than Korean rice.

Regarding aquatic and the terrestrial eutrophication potential, results for conventional rice farming in the U.S. were about 10 times higher than in Europe and Korea. In terrestrial eutrophication, Europe's rate was 4.14E-03 and the U.S. rate was 1.21E-02 mole of nitrogen equivalents (Figure 22). The terrestrial eutrophication potential from U.S.

rice farming was 292% higher than Europe's and 401% higher than Korea's. Aquatic eutrophication impact in the U.S. was about 20.75 times higher than in Europe, and about 5 times higher than in Korea for conventional rice farming (Figure 23).

Human toxicity, both cancerous and non-cancerous, had different results. In the case of cancerous human toxicity, conventional rice in the US showed low impact of 60% and 78% compared with Europe and South Korea (Figure 24). In addition, the potential of non-cancerous human toxicity for conventional rice farming in the US was 221%, 208% higher than that in Europe and that in Korea, respectively (Figure 25). This is thought to be due to the differences in the databases being used.

The particulate matter potential of conventional rice farming in the U.S. was 177% higher than in Europe and 242% higher than in Korea (Figure 26).

The photochemical ozone formation potential of conventional rice farming in the U.S. was 637% higher than in Europe and 677% higher than in Korea (Figure 27).

In the case of freshwater aquatic ecotoxicity, the United States was about 400% higher than in Europe and in Korea (Figure 28).

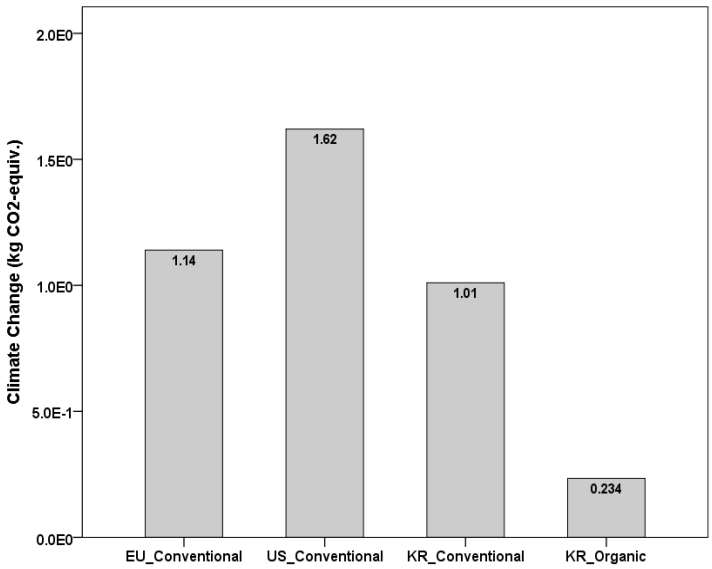


Figure 22 Climate Change Potential by Country

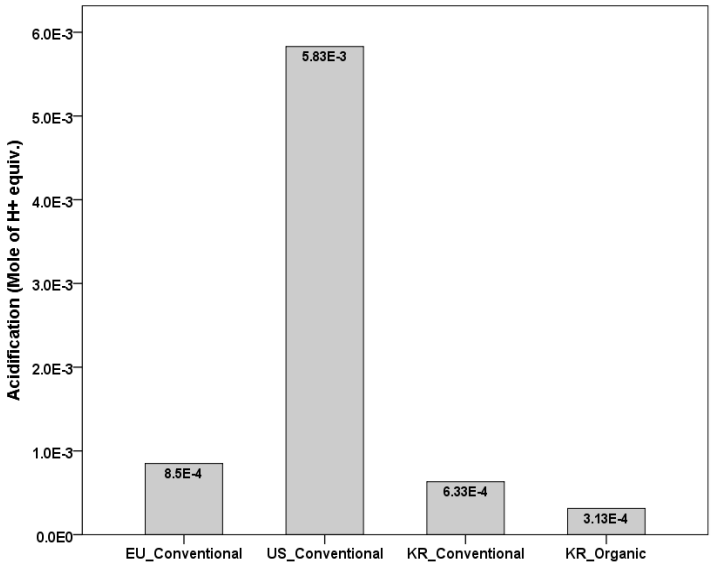


Figure 23 Acidification Potential by Country

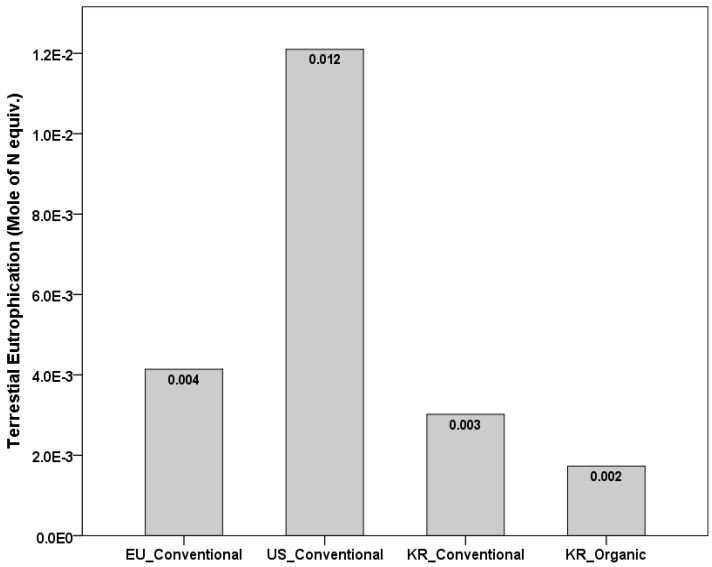


Figure 24 Terrestrial Eutrophication Potential by Country

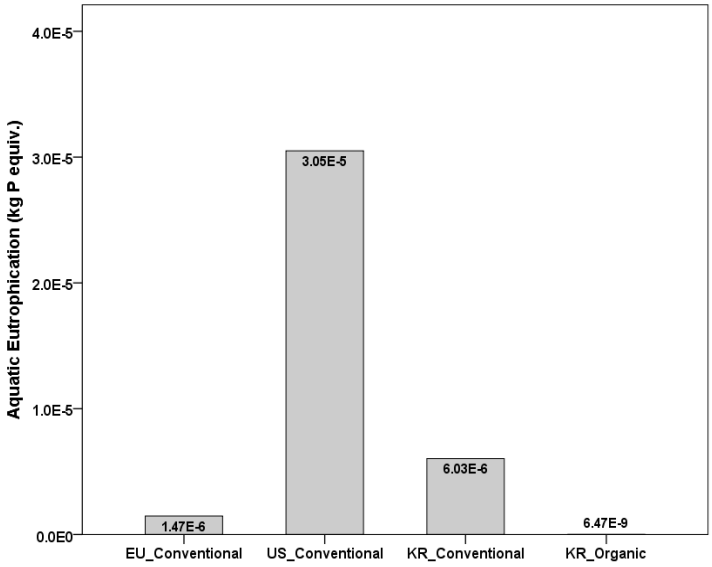


Figure 25 Aquatic Eutrophication Potential by Country

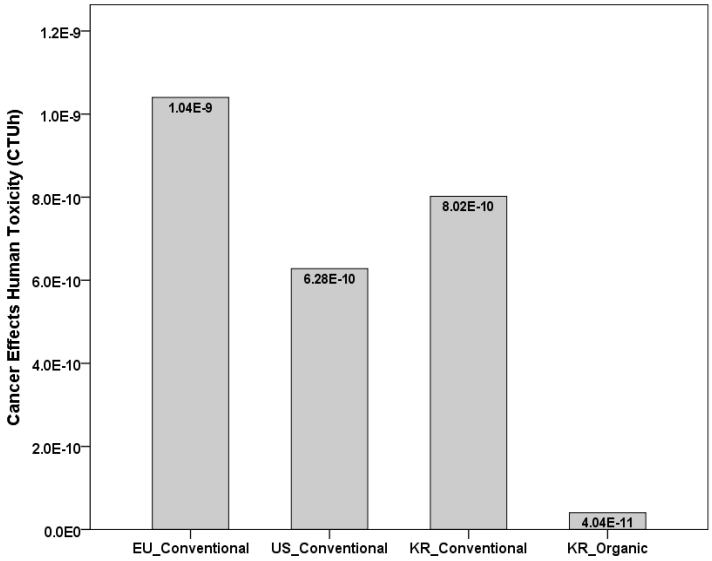


Figure 26 Cancerous Human Toxicity Potential by Country

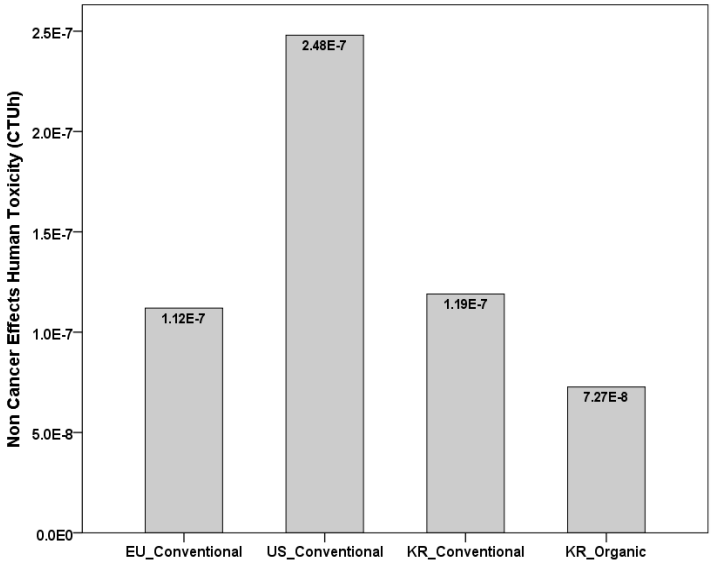


Figure 27 Non-cancerous Human Toxicity Potential by Country

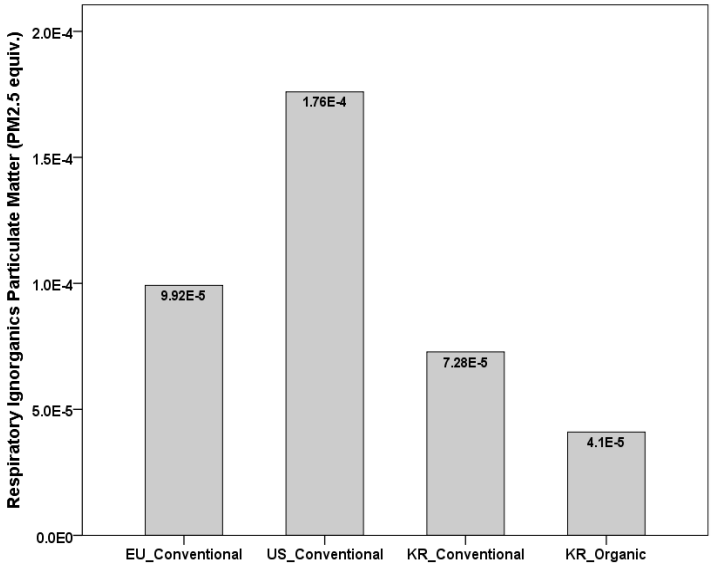


Figure 28 Particulate Matter (PM2.5) Potential by Country

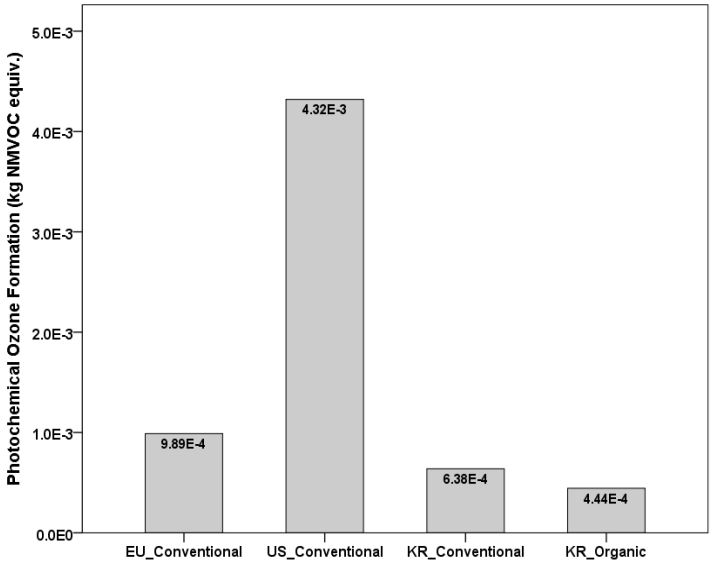


Figure 29 Photochemical Ozone Formation Potential by Country

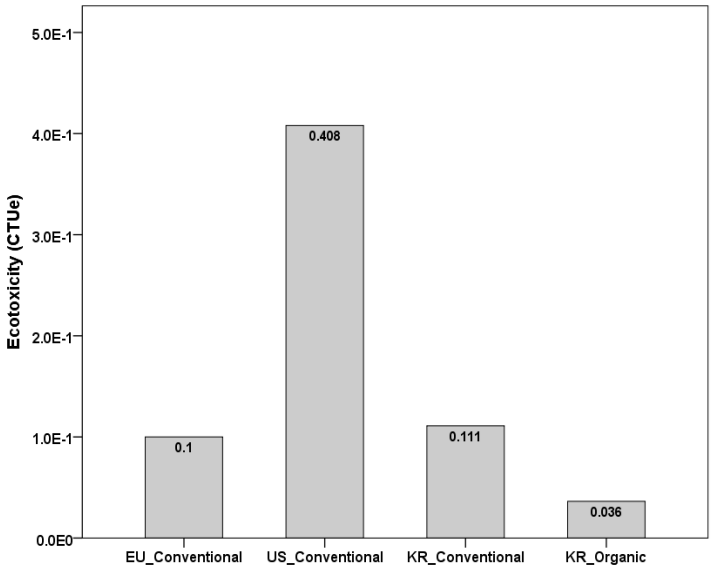


Figure 30 Freshwater Aquatic Ecotoxicity Potential by Country

5.2.2. Comparison of Normalized Environmental Implications

The normalization phase uses normalizing factors recommended by the ILDC to identify the issues considered substantive by countries in various environmental implications categories.

Post-normalization, the most pressing potential environmental indicator emerged as non-cancerous human toxicity potential among 9 environmental impact categories, followed by climate change potential, then photochemical ozone formation potential (Figure 29). All the environmental impacts of U.S. conventional rice farming are higher than Korean and European rice farming impacts except for cancerous human toxicity.

U.S. rice farming inputs such as fertilizer, agrochemicals, and energy were higher than those of other countries in this study. These amounts have a decisive influence on the environmental implications. However, the potential of cancerous human toxicity has low implications that considered influence by different database used and some kinds of fertilizer and agrichemicals. When assessing the environmental implications, the present study consulted the U.S. LCI provided by NREL for U.S rice farming figures and the Ecoinvent database was used for Korean and European rice farming figures.

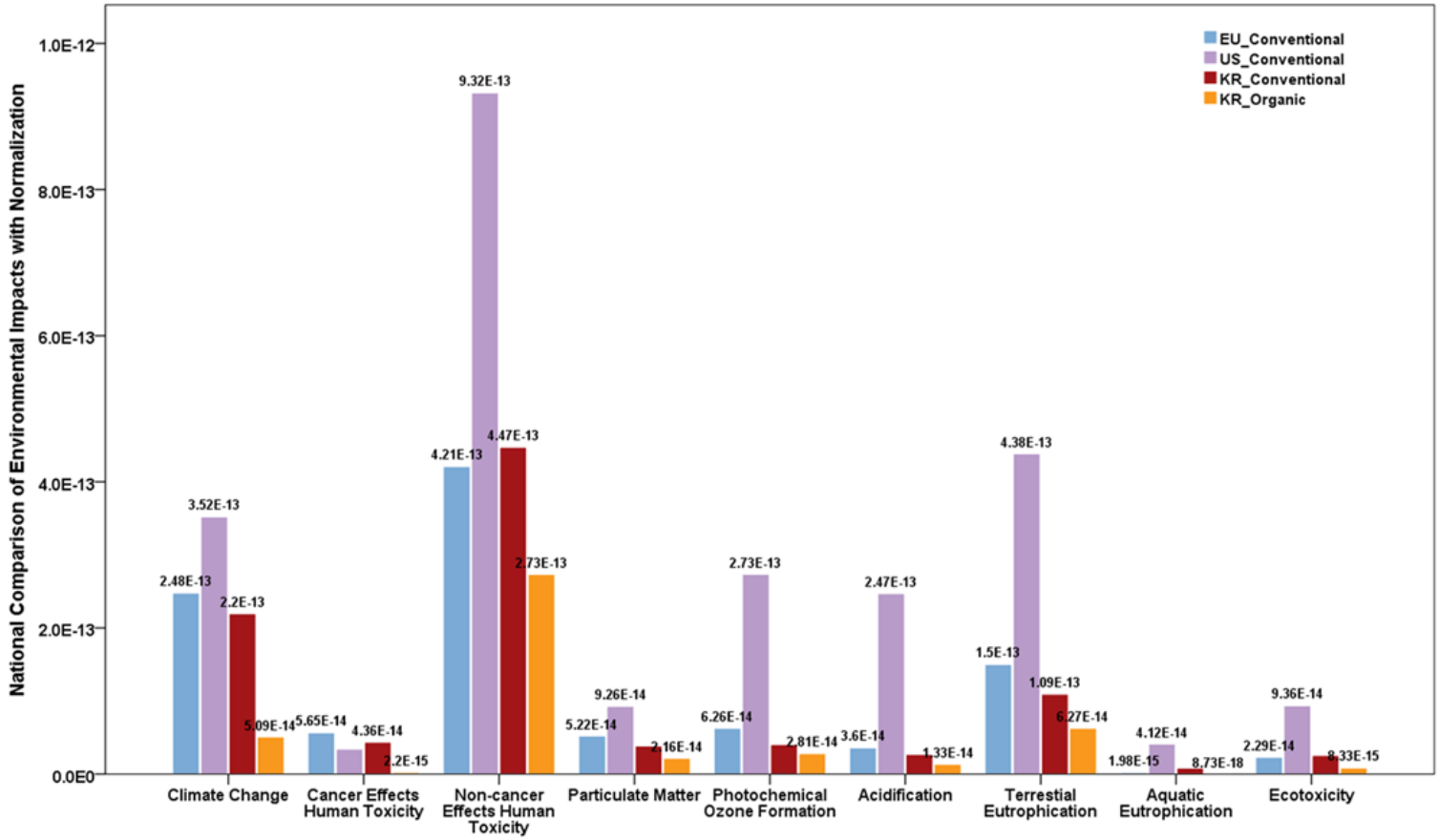


Figure 31 Normalized Environmental Implications by Country

5.2.3. Environmental Implications of National Rice Farming

The relative environmental influences of the production of environmentally-friendly rice in the three studied areas are as follows, when the impact value of conventional farming in the U.S. was set at 100 in weighting (Figure 30). The highest ranked impacts were by conventional farming in the U.S., followed by European (53.73) and Korean, which are conventional (48.56), low-pesticide (35.80), non-pesticide (28.93), and organic (16.66).

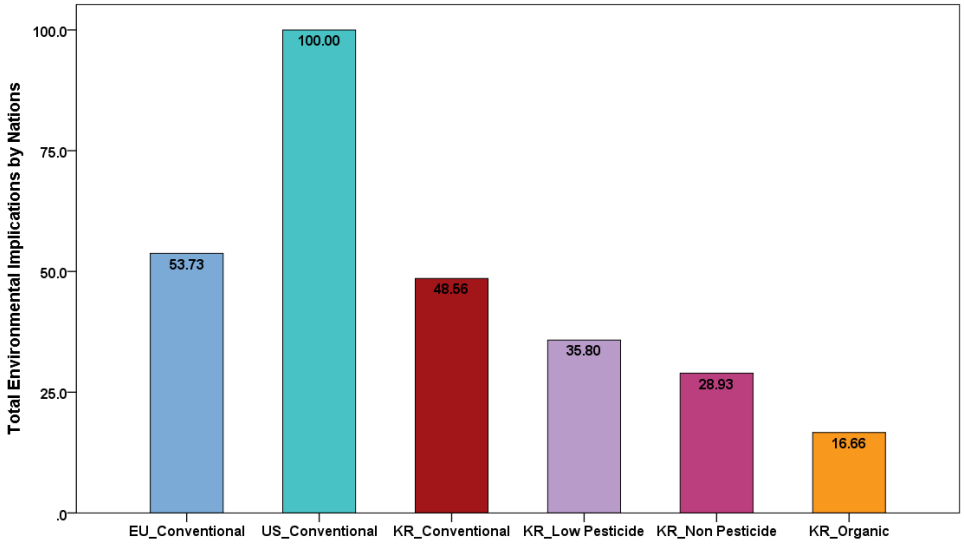


Figure 32 Environmental Implications by Country

CHAPTER 6. CONCLUSION

Regulations, standards, and certification systems aimed at the reduction of GHG in response to climate change have strengthened of late. The Paris Agreement in 2015 set GHG emissions reduction goals in accordance with the reduction target of several countries. Agriculture, like other sectors, is greatly impacted by new policies and regulations such as low carbon certification.

The greatest purpose of agriculture up to 1990 and beyond was to promote production volume. Farmers introduced more chemical fertilizers and agricultural chemicals than was strictly necessary to achieve this goal. This caused environmental problems such as strengthening pests' resistance to insecticides, increasing human and ecological toxic substances, acidifying soil, etc. Since then, the industry has begun to strive toward sustainable agriculture to achieve high input while minimizing environmental impacts.

Since agriculture, which is a carbon sink and source of emissions, has high uncertainty due to the nature of the industry, it is necessary to have an objective method to evaluate environmental impact. A Life Cycle Assessment (LCA), which quantitatively evaluates the environmental impact not only of the planting and harvesting process, but of the entire process from raw material production through transport and sales, is an effective tool for quantifying the total effect of agriculture on environmental change.

The LCA of the agricultural production system is considered from the

extraction of raw materials used to produce agricultural products to the production stage of agricultural products. For example, in the case of rice, which is the principal grain of Korea, raw materials (seeds) and energy (such as electricity, light, oil, etc.) are input is raised until crops are produced. Livestock raising, formal, cultivation, and auxiliary substances such as agricultural chemicals and fertilizers are added. During planting, cultivating, and harvest processes, emissions of carbon dioxide, methane, nitrous oxide, suspended particulate matter, and the like are generated, affecting the environment in various categories, including exhaustion of resources-which is affected by the introduction of raw materials, energy, and various agricultural materials-and global warming, ecotoxicity, acidification, and eutrophication, which are all impacted by emissions generated in agriculture. It is possible to effectively analyze and quantify the environmental influences of various inputs via the LCA method.

This study evaluated the environmental implications of eco-labelling for rice farming systems, including conventional, low-pesticide, non-pesticide, and organic rice farming. The eco-labelling for Korean rice farming systems was compared with the environmental implications of American and European conventional rice farming to identify how eco-friendly Korean rice farming compares to other countries' farming systems. The environmental impacts of Korean rice farming were quantitatively reviewed. LCA was also used for this study to evaluate the effects of environmental improvement, as it is important to consider the "life-cycle" of agricultural production. The results show that

eco-labelling systems can reduce the environmental impacts of farming.

The following environmental impact categories were selected to be evaluated: climate change, acidification, aquatic and terrestrial eutrophication with high relevance to various emissions occurring in the agricultural sector, cancerous human toxicity, non-cancerous human toxicity, particulate matter, photochemical ozone formation, and aquatic ecotoxicity.

For the classification stage, 9 impact categories associated with agriculture were chosen to evaluate the environmental implications of various rice farming systems. Korean rice farming systems affect climate change differently according to the farming method: conventional farming is 1.01E+00kg CO_2-equiv., while low-pesticide farming is 6.01E-01 kg CO_2-equiv., non-pesticide farming is 5.31E-01 kg CO_2-equiv., and organic farming is 6.58E-01 kg CO_2-equiv. Considering these results, when producing approximately 10% from 4.22 million tons of conventional rice annually for organic certification, organic farming is expected to reduce GHG emissions by more than 327 tons per year. Organic certified production (3.13E-04 mole of H^+ equiv.) yields about 51% less acidification than that of conventional rice production (6.33E-04 mole of H^+ equiv.). Regarding eutrophication of the water system, the reduction effect of organic growing (6.47E-09kg P-equiv.) is much greater than that of conventional rice (6.03E-06kg P-equiv.). Influence on other environments such as human toxicity index was analyzed, showing that environmentally-friendly agricultural certification systems are effective for reducing the environmental impact

of rice farming.

In order to quantitatively evaluate the various effect values calculated, each of these environmental impact categories were normalized based on the total amount of annual emissions by category occurring in 27 European countries. By normalizing for national rice farming, the most effective potential environmental indicator among 9 environmental impact categories is non-cancerous human toxicity potential. U.S. conventional rice farming impacts the environment at a higher rate than Korean and European rice farming in all environmental impact categories except for cancerous human toxicity.

By weighting for national rice farming, when the total environmental implications of conventional rice farming in the U.S. was established as 100, the relative environmental impacts are as follows: The environmental impact of conventional rice farming in Europe was 53.73 and the impact of Korean rice farming was 48.56 for conventional farming, 35.80 for low-pesticide farming, 28.93 for non-pesticide farming, and 16.66 for organic farming.

The present study had some limitations when conducting the LCA for eco-labelling. No unique LCI was available for agro-materials in South Korea. Thus, the figures for inventories of agro-materials were taken from the Ecoinvent inventory database using the same production process assumptions.

It should be noted that there is no LCI information available for materials such as fertilizer and pesticide in South Korea. For this reason, the Ecoinvent database was used to evaluate environmental

implications for Korean rice farming systems in this study. This is based on the assumption that Korean emissions are similar to those of European countries. The accuracy of the current study's results, therefore, depends on the similarity of materials from region to region, which may be affected by the different characteristics of the regions in question. There remains a need for primary research on LCI of agricultural materials such as fertilizer, other chemical input, and energy in South Korea. Once this data has been collected, future research on the environmental impact of rice cultivation in South Korea will be more accurate.

The results in this study support a recommendation of agricultural policies such as direct payment for environmentally-friendly farming, marketing for agri-food industries, and environmental assessment of the agricultural sector. In addition, these results may be useful in proliferating and improving methodology to evaluate eco-labelling and carbon labeling systems.

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국문초록

전과정평가 기법을 이용한 친환경농산물인증제도의 환경영향 평가

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기후변화 대응에 대한 관심으로 온실가스 저감과 관련한 규정, 표준, 인증제 등이 강화되고 있으며, 2015년 파리협정에서 신기후체제에 대응하기 위해 설정한 온실가스 감축목표에 따라 여러 나라에서 환경정책을 실시하고 있다. 온실가스 감축에 있어서 농업분야도 예외가 아니며, 이를 위해 친환경인증, 저탄소인증, 최적영농관리방안 등의 다양한 환경정책이 시행중이다. 그 중에서 친환경농산물인증제도는 농업분야에서 시행되고 있는 대표적인 환경정책 가운데 하나로 2001년 시행 이후 2015년 기준으로 3,574 농가가 참여하고 있다.

1990년 이전까지 농업의 가장 큰 목표는 생산량 증진이었으며, 이를 위해 화학비료 및 농약 등을 필요량 이상으로 투입해 왔다. 하지만 이로 인해 병충해의 내성강화, 인체 및 생태계 독성물질 배출, 토양산성화 등의 다양한 환경문제를 야기하면서 미래의 지속가능한 농업에 대한 관심을 가지고 노력

하기 시작하였다. 지속가능한 농업에 대한 관심은 현재의 생산성 향상을 위한 고투입 농업에서 환경영향을 최소화 할 수 있는 친환경농업으로 농업생산 시스템의 패러다임을 변화시키고 있다. 탄소의 흡수원임과 동시에 배출원인 농업은 산업의 특성상 불확실성이 높기 때문에 농업활동에 대한 환경영향을 객관적으로 정량화한 평가방법이 필요하다. 생산 공정 뿐만 아니라 원료의 생산부터 운송과 판매를 포함한 생산물의 전과정을 통해 환경에 미치는 영향을 정량적으로 평가하는 전과정평가 (Life Cycle Assessment, LCA)는 농업의 시스템 변화에 따른 환경개선효과를 효과적으로 정량화 할 수 있는 분석 도구이다.

농업생산 시스템에 대한 전과정평가는 농산물 생산에 사용되는 원료물질의 채취와 농산물 생산단계까지를 고려한다. 우리나라 대표 주곡인 쌀의 경우 기본적으로 원료물질인 종자 혹은 종묘를 투입하여, 육묘, 정식, 재배, 수확단계를 거쳐 농산물이 생산될 때 까지 전기, 경유와 같은 에너지와 농약, 비료 등과 같은 보조물질이 투입된다. 이러한 단계별 생산과정에서 이산화탄소, 메탄, 질소산화물, 미세먼지 등의 배출물이 발생하며 다양한 형태로 환경에 영향을 준다. 원료물질, 에너지, 각종 농자재 등의 생산재 투입은 자원고갈이라는 범주의 환경영향을 미치며, 생산단계별로 투입재로 인해 발생되는 배출물은 지구온난화, 생태독성, 산성화, 부영양화 등의 다양한 범주에 대한 환경영향을 야기한다. 이러한 농산물의 생산단계와 다양한 투입재로 인한 여러 범주의 환경영향을 전과정평가기법을 통하여 효과적으로 분석하고 정량화 할 수 있다.

1996년부터 전과정평가 기법이 농업분야에 적용되기 시작하면서 2000년대까지는 주로 단일 작물의 생산에 대한 과정이나 농자재 투입 및 배출에 대한 환경영향 평가가 수행되었으나, 2000년 이후로는 관행농과 유기농 생산체계 등과 같은 서로 다른 농업생산 시스템을 비교하는 연구가 수행되고

있다. 하지만 대다수의 관련연구는 농업생산 활동으로 발생될 수 있는 환경영향을 주로 온실가스 발생으로 인한 기후변화 영향에 한정하여 연구가 이루어져 왔으며 실제 발생할 수 있는 다양한 환경영향 범주에 대한 연구를 찾아보기 어렵다.

따라서 본 연구에서는 전과정평가기법을 이용하여 친환경농산물인증제도(무농약, 저농약, 유기농)에 따른 쌀 생산 과정의 환경영향을 정량적으로 평가하고 관행농을 포함하여 비교하였다. 국제표준화기구 ISO 14040 시리즈에 규격화 된 전과정평가 프레임워크에 따라 환경영향을 평가하였으며, 이를 미국과 유럽의 쌀 생산시스템의 환경영향과 다양한 환경영향 범주에 대해 비교 분석하였다.

본 연구에서의 전과정평가는 국제표준화기구에서 규정한 ISO 14040규정을 준수하였으며, 분석에는 GaBi를 사용하였고 Ecoinvent와 U.S. LCI, 그리고 국내 작물생산 투입관련 데이터 등을 포함하여 전과정 목록을 작성하였다. 먼저, 목적 및 범위설정 단계에서는 쌀 재배과정에서의 기능단위를 쌀 1kg으로 설정하고, 시스템경계는 쌀 1kg을 생산하기 위한 육묘, 정식, 재배, 수확단계를 모두 포함하여 설정하였다. 다음으로 전과정목록 작성을 위한 단계에서는 국내 LCI 구축을 위해 2014년 통계청 농축산물생산비조사(논벼) 자료 및 농촌진흥청과 통계청에서 수집한 농축산물소득자료를 사용하였으며, 화학농자재의 경우 한국농산물품질관리원에서 제시하고 있는 친환경농산물 인증제도의 기준 허용치의 최대값을 이용하였다. 특히, 합성농약의 경우 농촌진흥청에서 제공하는 작물별 농약 정보를 참고하여 벼에 사용하는 농약의 원제 및 유효성분별 투입량과 대기, 수계 및 토양의 배출 경로 분석자료를 이용하여 농약에 대한 LCI를 구축하였다. 분석의 마지막 단계인 전과정영향평가는 분류화(classification), 특성화(characterization), 정규화(normalization), 그리고 가중화(weighting) 과정을 통해 수행하였으며, 그

결과는 다음과 같다.

쌀 생산과정에 대한 환경영향을 평가하기 위하여 ILCD recommendations에서 제시하고 있는 다양한 환경영향 범주들 가운데, 농업분야에서 발생하는 다양한 배출물과의 관련성이 높은 기후변화지수, 산성화지수, 수계 및 토양 부영양화지수를 포함하여 암 유발 인체 독성지수, 인체 독성지수, 입자성 물질지수, 광화학적오존산화지수, 그리고 수계 생태독성지수를 평가 대상범주로 선정하였다.

기능단위인 쌀 1kg 생산을 위해 발생하는 환경영향을 범주별로 살펴보면 기후변화지수는 관행농이 1.01 kg CO_2-equivalents로 평가되었으며, 저농약 인증 생산의 경우는 0.701 kg CO_2-equivalents (69%), 무농약 인증 생산의 경우에는 0.537 kg CO_2-equivalents (53%), 유기농 인증 생산의 경우에는 0.234kg CO_2-equivalents (23%)가 발생하는 것으로 각각 분석되었다. 이러한 결과를 바탕으로 현재 연간 관행농 쌀 생산 422만 톤에서 약 10%를 유기농 인증으로 생산하는 경우 연간 327톤 이상의 온실가스 저감 효과를 기대할 수 있다. 산성화 지수의 경우에는 기존 관행농(6.33E-04 mole of H+ equivalents)에 비해 유기농 인증 생산(3.13E-04 mole of H+ equivalents)이 약 51%정도의 저감 효과가 있는 것으로 나타났으며, 수계 부영양화지수의 경우에는 관행농(6.03E-06kg P-equiv.)에 비해 유기농(6.47E-09kg P-equiv.)의 저감 효과가 매우 큰 것으로 분석되었다. 또한 인체독성지수 등과 같은 다른 환경영향에서도 관행농에 비해 친환경농산물 인증제도에 따른 쌀 재배가 환경영향 감소효과가 있는 것으로 분석되었다.

이러한 각각의 환경영향 범주별로 산정된 값이 실질적으로 미치는 영향을 정량적으로 평가하기 위하여 유럽 27개국에서 발생하는 범주별 연간 배출량의 총량을 바탕으로 정규화하였다. 정규화 결과 쌀 생산과정에서 배출되는 물질이 인체독성과 기후변화에 가장 큰 영향을 미치는 것으로 분석되었

으며, 관행농과 친환경인증제도에 따른 무농약, 저농약, 유기농 쌀의 가중화를 통한 종합적인 환경영향으로 산정하는 경우 관행농을 100으로 기준으로, 저농약 인증(73.73), 무농약 인증(59.57), 유기농 인증(34.31) 순으로 영향을 미치는 것으로 분석되었다.

미국 U.S. LCI와 유럽 Ecoinvent 데이터베이스에서 제공하고 있는 쌀 1kg 생산 기능단위에 대한 환경영향 자료를 바탕으로 한국, 미국, 유럽에서 생산되는 쌀의 생산과정에 대한 환경영향을 비교하면, 미국을 기준(100)으로, 유럽은 53.7로 평가되었고, 한국산 쌀의 경우 관행농은 48.6, 저농약 인증은 35.8, 무농약 인증은 28.9, 유기농 인증은 16.7로 각각 분석되었다.

본 연구에서 국내에서 생산되는 쌀의 전과정평가를 위해 구축된 전과정목록은 관행농 생산에 대한 투입물에 대한 자료를 바탕으로 친환경인증제도의 기준에 따른 비료, 농약 등의 농자재 투입량 기준을 바탕으로 전과정목록을 분석하였다. 하지만 현재 우리나라의 경우 비료, 농약 등 투입물에 대하여 사용가능한 국내 전과정목록이 없어 여러 유럽국가에서의 농자재 생산과정에서 발생하는 배출량과 유사하다는 가정 하에 범용적으로 사용되고 있는 에코인벤트 데이터베이스에서 제공하는 자료를 사용하였다. 본 연구의 분석대상인 농산물의 경우 생산국가의 특성에 대한 고려가 중요한 요소임을 생각하여 해석과정에 민감도 분석 등을 통하여 자료의 차이에 따른 영향을 반영하였으나 실재로 조사된 데이터베이스의 부재에 따른 자료의 한계가 존재한다고 판단된다. 따라서 향후 보다 객관적이고 신뢰성 있는 평가결과 도출과 다른 국가들과의 생산과정의 환경영향을 비교하기 위해서는 상위공정을 포함한 전과정의 투입물과 산출물 데이터를 바탕으로 우리나라 고유의 전과정목록(Lifecycle Inventory)을 구축이 요구된다고 판단된다. 이후 비료, 농약 등의 화학농자재와 에너지 등에 대한 인벤토리 구축과 관련된 연구와 함께 다양한 농산물에 대한 전과정평가기법을 통한 환경영향을 지속적으로 진

행할 필요가 있다고 생각된다.

본 연구를 통해 평가된 결과는 향후 농식품기업의 마케팅, 농업분야의 환경성 평가, 친환경농업직접지불제 등 다양한 농업정책의 기초자료로써 제공이 가능하며, 환경라벨링 혹은 탄소라벨링 제도의 보급 확산 빛 방법론 개선 등에 적극적인 활용이 가능할 것으로 사료된다.

Keywords : 전과정평가, 지속가능한 농업, 환경영향, 친환경농산물인증제, 에코라벨링

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